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YEAR THIS DEGREE GRANTED ..... 1971 .....

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MODEL STUDY OF THE BASEKT-TYPE
BED-LOAD SAMPLER

by

© CHARLES J. GIBBS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

FALL, 1973

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Model Study of the Basket-type Bed-load Sampler submitted by Charles J. Gibbs in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

To check the performance of basket-type bed-load samplers, a 1 to 5 scale model of a sampler with two different mesh sizes was tested in a flume under flow conditions modelled on the basis of field results obtained during earlier studies. An analysis of the model data indicates that sampling efficiency increases with transport rate. The effect of sample size on accuracy is examined and a minimum of 20 samples is recommended to give a satisfactory estimate of mean transport rate. Optimum sampling durations are also suggested by determining the loss of sampling efficiency as the sampler fills.

The time-distribution of sampler catch is analyzed and it is found that the square root of sampler catch is normally distributed in time. The two dune-type bed-forms observed during the tests are described.

ACKNOWLEDGMENTS

The author wishes to express his sincere thanks to Mr. C.R. Neill of the Research Council of Alberta and to his supervisor Dr. R. Kellerhals for the guidance and encouragement which they provided throughout this study.

The major portion of the financial support was provided by the Inland Waters Branch, Environment Canada, Ottawa, through a contract with the Research Council of Alberta. Some additional support was received from the Research Council of Canada.

Special thanks are extended to Mr. A.L. Charbonneau, Dr. R.H. Cooper, and the staff of the graduate hydraulics laboratory for their assistance in setting up and conducting the model tests.

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NOTATION

b	-	flume breadth (ft)
C	-	cross-sectional average bed-load concentration by weight (ppm)
C_{bt}	-	total bed-material load concentration by weight (ppm)
$C_{\mathbb{C}}$	-	centreline average bed-load concentration by weight (ppm)
C_r	-	catch rate (lb/min)
D	-	geometrical mean grain size diameter (ft)
D_{mn}	-	effective sediment diameter (ft)
D_p	-	grain diameter for which p % of distribution is less than (usually mm)
d	-	dimensionless parameter for comparison of means test
E	-	sampling efficiency (percent)
F'_r	-	densimetric Froude number (dimensionless)
fn	-	function of
G_s	-	bed-load discharge rate by weight (lb/min)
g	-	acceleration of gravity (ft/sec^2)
g_s	-	unit width bed-load discharge rate [lb/(min-ft)]
h	-	depth of flow (ft)
K_b	-	Strickler roughness coefficient for the entire bed (ft$^{1/3}$/sec)
K'_b	-	Strickler roughness coefficient for bed-material grains only (ft$^{1/3}$/sec)
k_s	-	equivalent sand grain roughness diameter (ft)
n	-	Manning's roughness coefficient (ft$^{1/6}$ or dimensionless)
Q	-	fluid discharge by volume (ft^3/sec)
q	-	unit width fluid discharge [ft^3/(sec-ft)]
R	-	hydraulic radius (ft)
S	-	bed slope (dimensionless)
$S_{\bar{x}}$	-	standard deviation of sample [lb/min or lb/(min-ft)]
$S.G._s$	-	specific gravity of bed-material particles (dimensionless)

V or Vm - cross-sectional mean velocity (ft/sec)

$V_{\mathbb{C}}$ - centreline mean velocity (ft/sec)

V_* - shear velocity (ft/sec)

Vi - $\frac{D_{50}\ \sqrt[3]{\nu g}}{\nu}$ (dimensionless)

x - dimensionless parameter in the logarithmic velocity distribution law

$\bar{x}$ - sample mean (lb/min or lb/(min-ft))

Greek

γ - unit weight of fluid (lb/ft^3)

γ_b - unit weight of bed-material (lb/ft^3)

γ_b' - submerged unit weight of bed-material (lb/ft^3)

θ - $\tan^{-1} \frac{S_{\bar{x}_1}}{S_{\bar{x}_2}}$ (degrees)

ν - kinematic viscosity of the fluid (ft^2/sec)

ρ_f - fluid density ($slugs/ft^3$)

ρ_s - density of bed-material particles ($slugs/ft^3$)

σ_b - bed-material gradation (dimensionless)

ϕ_* - dimensionless intensity of bed-load transport

Ψ_* - Einstein's dimensionless shear stress parameter

Ψ_m - Colby and Hubbell's dimensionless shear stress parameter

CHAPTER 1

INTRODUCTION

1.1 Basket-type Bed-load Samplers and Their Use

In recent years several agencies in the Federal and Provincial Governments have been interested in determining the effects of sediment movement on reservoir storage, navigation, power development, etc. This has led to the use of bed-load samplers in an effort to estimate the amount of material moving in close proximity to the bed of river channels (the so-called bed-load). Difficulties in interpreting field sampling results prompted the present study, in which scale models of bed-load samplers were tested under various flow conditions in a flume.

The bed-load sampler most often used for sampling of coarse bed-load in Alberta rivers has been the basket-type sampler. The large size basket-sampler consists of a rectangular frame and tail section into which a basket with one open end is fitted. It has an overall length of 70 in. and weighs approximately 240 lbs. Plate 1-1 is a side view of this sampler with a ¼-inch mesh basket. It is lowered onto the bed of a river from a cable way or bridge. After remaining there for a specified duration, it is raised, weighed and the sample removed. The sampling is repeated a

number of times at each section across the river to arrive at an estimate of the bed-load discharge.

Problems arise from the fact that this sampler catches only a fraction of the bed-load which would normally go through the section if it were not there. This fraction, when expressed as a percentage is generally known as the sampling efficiency, E. Model studies conducted up to this time have yielded efficiencies which appear unsatisfactory when applied to field data.

1.2 Objectives of the Study

This model study of the behaviour of the basket-type bed-load sampler had the following objectives:

(1) To determine the average efficiencies over a range of flow conditions of one basket-type bed-load sampler, using baskets of two different mesh size.

(2) To provide data on the large temporal variability of transport rate at a point.

(3) To determine the number of samples necessary to obtain a satisfactory estimate of the average transport rate.

(4) To determine the effect of sampler fullness on efficiency, by varying the duration of sampling.

(5) To compare apparent bed-load size distributions as obtained by various bed-load sampling techniques.

(6) To evaluate the effects of scaling through the comparison of the model results with field data.

(7) To suggest efficient field procedures.

(8) To provide information on bed-forms.

(9) To test three procedures for computing bed-load transport.

CHAPTER 2

BACKGROUND TO THE STUDY

2.1 Previous Experimental Studies of Bed-load Sampler Efficiency

A number of basket-type bed-load samplers were designed and tested in Europe during the period from 1930 to 1940. Hubbell (1964) has summarized this early work and it is from this source that the following information is abstracted. Ehrenberger, in testing his own design, shown in Fig. 2-1-A, reported sampling efficiencies of from 83 to 100 percent. These values were later revised to 62 percent on the basis of Einstein's experiments. Einstein, working with the Nesper sampler, shown in Fig. 2-1-B, recommended an average sampling efficiency of 45 percent, but reported an efficiency range of 20 to 90 percent depending on the grain size of the bed-load and on flow conditions. Hubbell summarizes these early studies by suggesting an average efficiency of 45 percent for all basket-type bed-load samplers.

In 1957 Novak (1957) reported on the development and testing of a new pressure difference sampler. While conducting model tests on the new sampler he also tested basket-type samplers to check their reported sampling efficiencies. For a wire mesh type, (not shown in publication), Nesper type and Ehrenberger type, Novak

reported efficiency values of 65, 40 and 60 percent, respectively.

Along with these efficiencies, Novak made note of the following general conclusions:

(1) Sampling efficiency was unaffected by grain diameter if the bed material was of uniform size.

(2) Of the basket-type samplers, only the wire mesh sampler had a catch which was representative in grain size of the actual bed-load moving.

(3) The height of the bottom leading edge is an important factor in determining the smallest particles that can enter the sampler.

2.2 Available Canadian Field Data

Field studies with bed-load samplers have been conducted on two gravel rivers in the Rocky Mountain foothills of Alberta (Hollingshead, 1968, Hollingshead, 1971, Samide, 1971). The 1968 study involved a reach of the Elbow River at Bragg Creek, while the 1971 study continued this work and initiated a study of the North Saskatchewan River at Nordegg. In both cases samplers of the basket-type and Novak's pressure difference type were used.

In the course of the Elbow River study, a large pit was excavated in the river bed. This was assumed to catch close to 100 percent of the bed-load. By

surveying the pit at regular intervals, average transport rates and average bed-load sampler efficiencies could be determined. Estimated sampling efficiencies of a ¼-inch mesh basket sampler for various fluid discharges, as given by Samide (1971), are shown below (data from Elbow River study):

Elbow River Discharge (c.f.s.)	Efficiency (percent)
1200	0
1400	35
1600	45

For flows in excess of 1600 c.f.s. a survey of the pit was not possible. The efficiency of the ½-inch mesh basket was assumed to remain constant at 45 percent for higher discharges. A second basket mesh size of ½-inch, also employed in the 1971 study, gave an indicated efficiency of 60 percent at 1600 c.f.s.

In both studies it was noted that because of fluctuations of bed-load transport at a point with respect to time, it was necessary to take a considerable number of samples to obtain acceptable estimates of average transport.

2.3 Statistical Analysis of Bed-load Discharge Data

In a study of sediment discharge variability on the Kura River delta (Shteynman, 1966), it was found

that the distribution of bed-load discharge values as determined by sampling followed a Gaussian law. This result was also derived analytically by assuming that the displacement of bed particles was caused by the occurrence of velocity impulses on the bed, which were random in time and magnitude. Using the limiting theorem of probabilities, it was concluded that pulsations of bed-load discharge, travelling in the form of dunes should conform to the Gaussian distribution law.

A final observation of the Kura River delta report was that the average transport rate obtained from 20 samples was essentially equal to the average obtained from 100 samples.

2.4 Analysis of World-wide Flume Transport Data

In a study of world-wide flume data (Cooper, 1970), a functional relation was developed to describe the behaviour of flow in alluvial channels. It was given as:

$$0 = \text{fn}\ (F_r', C_{bt}, \frac{h}{D_{50}}, Vi, \frac{b}{h}, \sigma_b)$$

$$0 = \text{fn}\ (S, C_{bt}, \frac{h}{D_{50}}, Vi, \frac{b}{h}, \sigma_b)$$

in which

h is the flow depth

b is the flume width

D_{50} is the median grain size diameter of the bed-material.

S is the bed slope.

$$C_{bt} = \frac{G_s}{Q\gamma}$$

where G_s is the bed-material discharge by weight

Q is the fluid discharge by volume

γ is the unit weight of the fluid

$$F_r' = \frac{\rho_f V^2}{\gamma_b' h}$$

where V is the mean fluid velocity

γ_b' is the submerged unit weight of the bed-material.

ρ_f is the mass density of the fluid.

$$Vi = \frac{D_{50} \sqrt[3]{\nu g}}{\nu}$$

where ν is the kinematic viscosity of the fluid

g is the acceleration of gravity

$$\sigma_b = \tfrac{1}{2} \left(\frac{D_{84}}{D_{50}} + \frac{D_{50}}{D_{16}}\right)$$

where D_{84} is the grain size for which 84 percent of the bed-material is finer.

D_{16} is the grain size for which 16 percent of the bed-material is finer.

An analysis of the flume data indicated that if Vi and $\frac{b}{h}$ were large as in most of the flume tests they had little effect on the relations. σ_b was found to have an effect on the F_r'-C_{bt} relation, but the variations were unsystematic and in many cases corresponded to a change in the data source. With these simplifications, the relations reduce to:

$$0 = fn\ (F_r',\ C_{bt},\ \frac{h}{D_{50}})$$

$$0 = fn\ (S,\ C_{bt},\ \frac{h}{D_{50}})$$

The final form given by Cooper consisted of plots of two of the variables with contouring for the third (see Fig. 2-2). The curves without correction are applicable for material having a specific gravity of 2.65.

These plots provide a convenient means by which the flow conditions for a flume trasport study can be planned. After the values of the median grain size diameter (D_{50}), bed-material discharge (G_s) and depth of flow (h) are decided upon, an estimate of the fluid discharge and initial flume slope can be obtained through the use of the plots. Upon completion of the experiments, the data obtained can be checked against the plots.

CHAPTER 3

EXPERIMENTAL DESIGN AND PROCEDURES

3.1 Experimental Modelling

Sampling data obtained from two studies of the Elbow River at Bragg Creek, as mentioned in Section 2.2, gave an indication of the performance of basket-type bed-load samplers under specific field conditions. The present study was designed to check this indicated performance by conducting laboratory sampling under flow conditions modelled on those reported in the field studies.

3.1.1 Scale Determination

The geometrical conditions necessary to define a two-phase flow problem, such as the phenomenon under consideration here, are given by Yalin (1965) as follows:

(i) the shape of the cross-section of flow,

(ii) the shape of the particles of the bed material,

(iii) the shape of the particle-size distribution curve of the bed-material.

The phenomenon is then defined by specifying the following:

(a) fluid characteristics: kinematic viscosity, ν; fluid density, ρ_f.

(b) bed material characteristics: a particular grain size, D_p (usually D_{50}); density of the bed-material particles, ρ_s

(c) any two of the following flow characteristics: depth, h; slope, S; mean velocity, V; total bed material transport rate, G_s

(d) gravitational characteristics: acceleration of gravity, g.

Any other flow property A is determined from the following relation:

$$A = f_n\ (\nu,\ g,\ \rho_f,\ D_{50},\ \rho_s,\ V,\ h)$$

Non-dimensionalizing we have:

$$\Pi_A = \phi_A\ \left(\frac{h}{D_{50}},\ \frac{\rho_s}{\rho_f},\ \frac{Vh}{\nu},\ \frac{V^2}{gh}\right)$$

Yalin (1965) states that for $\dfrac{D_{50}\ V_*}{\nu}$ (where $V_* = \sqrt{g\ Sh}$) values greater than 70, the relation no longer depends on ν. A check of field data revealed this to be the case so that the above relation reduces to:

$$\Pi_A = \phi_A\ \left(\frac{h}{D_{50}},\ \frac{\rho_s}{\rho_f},\ \frac{V^2}{gh}\right)$$

For the same bed-material particle density and fluid density in model and prototype, the Froude number $\frac{V^2}{gh}$ controls the modelling of the bed-load transport phenomenon.

The size of the Elbow River and large lateral variability of transport rate prohibited modelling the entire river. A length scale of 1:5 was determined by comparing the width of the flume available with a 20 foot slice of the river. Froudian modelling then fixed the time scale as $1:\sqrt{5}$ and the mass scale as $1:5^3$. Table 3-1 is a list of parameters and their scales as determined from the length, time and mass scales.

TABLE 3-1 LIST OF PARAMETERS AND SCALES

(1) Parameter	(2) Symbol	(3) Scale
Depth	h	1:5
Grain Size Diameter	D	1:5
Total Bed-load Discharge	G_s	$1:25\ \sqrt{5}$
Unit Bed-load Discharge	g_s	$1:5\ \sqrt{5}$
Mean Velocity	V	$1:\sqrt{5}$
Total Fluid Discharge	Q	$1:25\ \sqrt{5}$
Unit Fluid Discharge	q	$1:5\ \sqrt{5}$

3.1.2 Depth and Grain Size Modelling

In the field both the depth and mean velocity vary with discharge. Due to the restrictions of time it was not possible to investigate what influence both of these variables had on sampling efficiency. The

depth was thought to be less important and was therefore held constant in the model testing. Data from the Elbow River studies gave an average depth of flow of 2.45 ft. for the discharges sampled (in the region where bed movement occurred). This resulted in a model depth of approximately .55 ft.

The grain size distribution of the Elbow River bed-load as determined from the 1968 pit excavations and the basket samplers (see Hollingshead, 1971) are shown as Curves (a) and (b), respectively, in Fig. 3-1. Curve (c) is the true model bed-material obtained by scaling down Curve (b) on the 1:5 length scale. Curve (d) is the distribution which was available for use in the flume. It was obtained by combining a sand-gravel mixture, which had been sieved on a #18 screen, with a uniform small gravel. This material and the flow conditions studied, produced particle Reynolds' numbers which were greater than 70, so that the Froudian modelling remained valid.

3.1.3 Bed-load Sampler Modelling

The full size basket sampler with 2 mesh sizes was reduced to 1:5 scale to

produce the model samplers used in this study. Model and prototype dimensions of the sampler basket (without frame) are given in Table 3-2.

TABLE 3-2 MODEL AND PROTOTYPE BASKET DIMENSIONS

(1) Dimension	(2) Prototype Basket	(3) Model Basket
length	30 inches	6 inches
width	24 inches	4.8 inches
height	10 inches	2 inches

Table 3-3 gives the prototype sampler basket-screen openings (Col. 2), the 1:5 scale model basket-screen openings (Col. 4) and the screen openings of the wire mesh used in the model samplers (Col. 5).

Details of the model sampler are shown in Fig. 3-2. The sampler frame and two basket types can be seen in Plate 3-1.

3.1.4 Bed-load Discharge Range to be Studied

Due to time limitations it was only feasible to study three flow conditions. The capacity of the equipment determined the maximum transport rate studied, while the lowest rate was limited by the necessity of keeping

the sampling duration reasonable short. A third transport rate was selected in the middle of these two extremes. After a rough estimate of bed-load discharge had been made for the medium and low flow conditions, the initial flume slope and fluid discharge was obtained from the curves presented by Cooper (1970), as discussed in Section 2.4. Since only three flow conditions could be tested, the effect of varying both velocity and depth could not be properly studied. Therefore, the velocities were changed in each flow condition and the effects of depth variation were left for future study.

3.2 Flume Set-up

Fig. 3-3 shows a simplified diagram of the flume and the two pumping systems employed in the study. An overall view of the flume can be seen in Plate 3-2.

The sediment system, shown in red on the diagram, included a bed-load capture slot located at the downstream end of the flume, which funnelled the material transported over the end of the bed into a Wilfley sediment pump. A sediment-water mixture was returned to the upstream end of the flume through a 4 inch diameter pipe. Here the mixture entered the injection tank shown in Plate 3-3. After passing

through the two chambers provided for distribution of the material across the flume width, it was dropped to the bed for transport by the main fluid flow.

The area of the bed where sediment injection occurred was stabilized by a sheet of wire mesh to prevent scour by the flow dropping from the injection tank. A 4 inch electromagnetic flow meter monitored the total discharge in the sediment system, with the output feeding into a two channel discharge recorder. This system was run at maximum discharge to prevent accumulation of sediment in the lines or pump.

The second pumping system for sediment-free water supplied the major part of the discharge. A two-stage, axial-flow pump transported water from the sump at the downstream end of the flume to the head tank, through a 14 inch diameter pipe. From here it flowed through the flume and re-entered the sump through an overflow chute provided with a back-up screen to catch any bed-load which jumped over the capture slot. A 14 inch electromagnetic flow meter was used to measure the discharge, with the output feeding to the second channel of the discharge recorder.

Plate 3-4 is a view of the downstream end of the flume showing the main pump motor, gate valve and return line for the water system. The return line, gate valve and electromagnetic flow meter for the

sediment system along with the discharge recorder can also be seen.

The flume slope was varied by means of screw supports located at intervals along the flume. These supports were connected by a power driven chain and gear system. The depth of water in the flume was controlled by a tail-gate assembly at the downstream end (see Fig. 3-3).

3.3 Bed Slope, Water Surface Slope and Depth Determination

Fig. 3-4 shows a simplified diagram of an optical bed-sensing probe used to plot bed profiles. By measuring the intensity of reflected light, a servo system kept the probe at a constant distance from the bed. It was mounted on a carriage which rode on rails above the flume. The analog outputs of the probe and carriage were fed to a 2 channel X-Y recorder. Fig. 3-4 indicates the two types of plots obtained with this equipment. The horizontal and vertical scales of the dune plots were exaggerated to show the dune dimensions more clearly.

Fig. 3-5 is a simplified diagram of the probe used to obtain plots of the water surface profile. This probe sensed the location of the water surface through the variation in conductivity of the element as it entered and left the water. It was mounted on the same carriage as the bed-sensing probe and the

output was fed to the second Y channel of the recorder. With this arrangement one traverse of the carriage produced both a bed and water surface plot. The two Y-channels were calibrated in such a manner that the distance between the two profiles represented the depth.

Plate 3-5 shows an overall view of the flume carriage with the bed-sensing probe on the left and the surface-sensing probe on the right.

3.4 Bed-load Measurement Apparatus

The basket-type bed-load sampler with two basket types comprised the first method of measuring bed-load transport. The cross-section at which samples were collected was approximately 15 feet upstream of the bed-load capture slot. Sampling was limited to the flume centreline in order to be as free of wall effects as possible.

With basket sampling being carried out on the flume centreline only, it was necessary to obtain an estimate of the true local bed-load transport rate in the central strip. This was done with a slice sampler located on the centreline of the bed-load capture slot (see Fig. 3-6-A and 3-6-B), which diverted a .35 ft. wide slice of bed-load through a 1½ in. ID copper pipe. The flow from this pipe was sampled using a container with a wire mesh bottom. The end of the pipe was fitted

with an orifice to control the diverted discharge.

Plate 3-6 is a photograph of the slice sampler as seen looking into the bed-load capture slot and Plate 3-7 shows sampling of the diverted flow.

A third type of bed-load measuring apparatus, consisting of a cart which ran on the flume carriage rails, was used to estimate the total bed-load transport. This apparatus sampled the sediment-water flow at the upstream end. Plate 3-8 shows the cart in the sampling position. It consisted of a central chamber separated from two chambers on either side by wire mesh. The jet was directed into this central chamber which retained the sediment and allowed the water to pass through to the side chambers and back into the injection tank.

The length of the sampling durations was determined from the desired basket sampler fullness. This was done much the same as in the field; that is, a number of samples were taken at the start of the test and the duration was adjusted if need be. A sufficient number of samples had to be collected to allow the passage of a number of bed forms. Field sampling had indicated 20 samples to be sufficient; however, to check this, 50 samples were collected with the slice and basket samplers and 25 with the cart sampler.

3.5 Velocity Measurements

The transport prediction techniques which were compared with the bed-load sampling results required the use of a mean velocity on the flume centreline. The upper half of Fig. 3-7 is a simplified diagram of the arrangement used to measure mean velocity. A Prandtl-type pitot tube with 1 mm diameter orifice mounted on the flume carriage was used to obtain velocity profiles where the basket sampling was carried out. The lower portion of Fig. 3-7 indicated the path followed by the pressure signals in getting to the X-Y plotter.

3.6 Test Procedures and Sequence

Test procedures were as follows:

(1) Set the initial flume slope, water discharge and depth of flow, as determined according to Section 3.1.4 and allow the flume to run for several days, to permit the bed-material transport rate and bed slope to reach equilibrium.

(2) Collect 25 samples of bed-load inflow using the cart sampler described in Section 3.4.

(3) Obtain longitudinal water surface and bed profiles at three locations across the width of the flume, using the probes described in Section 3.3.

(4) Collect 50 basket samples on the flume centre-line using a constant sample duration and a constant interval between samples.

(5) Repeat Step (4) for the second size of basket mesh, using the same sampling duration.

(6) Collect 50 samples of bed-load outflow using the capture slot slice sampler described in Section 3.4, with the same sampling duration as in Step (4).

(7) Repeat Steps (4), (5) and (6) for two new sampling durations, retaining the same interval between the finish of one sample and the start of another.

(8) Using all three types of sampling apparatus, collect a number of samples for sieve analysis and water content determination.

(9) Take 20 velocity profiles on the flume centre-line, using the velocity probe described in Section 3.5.

(10) After shutting down the flow, plot longitudinal dune profiles at two locations across the flume width.

(11) Re-run the flume for several hours and re-plot profiles.

(12) Measure the rate of advance of several dunes in the sampling region.

(13) Repeat Step (3) to check for depth and slope variations.

Steps (1) to (13) were carried out for three different flow conditions.

CHAPTER 4

OBSERVATIONS AND RESULTS

4.1 Depths and Slopes

Using the water surface sensing and bed sensing probes described in Section 3.3, six longitudinal profiles of the water surface and bed surface were obtained for each flow condition over an 87 foot length of flume. Fig. 4-1 shows two typical examples of these profiles. The first 8 foot section of the flume was excluded from the profiles because of the proximity of the sediment injection tank.

In determining mean slopes of the bed and water surface, the inial 15 feet of each profile had to be neglected, since in many cases the elevations were being influenced by the injection of sediment in this region.

Table 4-1 gives the bed slope, water surface slope and depth of flow for each of the profiles taken during the three flow conditions. Average values for each flow condition are also given.

4.2 Velocity Observations

Twenty velocity profiles for each flow condition were taken on the centreline of the flume at the bed-load sampling section, using the velocity probe described in

Section 3.5. Fig. 4-2 shows one of the velocity profiles taken during flow condition no. 1. The mean velocity for each plot was determined graphically.

Table 4-2 gives the range of centreline mean velocities found for each flow condition (Col. 2), along with the arithmetic average of the 20 velocity values (Col. 3). The cross-sectional mean velocity (Col. 4), computed by dividing the discharge by the cross-sectional area of flow, is also given.

TABLE 4-2 MEAN VELOCITY DATA

(1) Flow Condition No.	(2) Range of Mean Velocities-Flume ₵ ft/sec.	(3) Average Mean Velocity-Flume ₵ ft/sec.	(4) Cross-sectional Mean Velocity ft/sec.
1	3.02 - 3.56	3.34	2.60
2	2.60 - 2.95	2.78	2.47
3	3.16 - 4.01	3.57	3.14

4.3 Grain-Size Analyses and Water Content Determination

4.3.1 Grain-Size Analyses of Bed-Material in Place

Volumetric samples of the bed-material were taken prior to testing to check how well it modelled the Elbow River bed-load (see Section 3.1.3). Fig. 4-3 gives the average results of the analysis of this set of bed-material samples.

Plate 4-1 shows bed layering as it existed in the third flow condition. The inter-

face seen in the photograph represents the division between a coarse active layer and a somewhat finer passive layer. The active layer consisted of material which had recently been deposited on the advancing face of a dune. At the conclusion of the tests samples for sieving were taken from the active layer to determine if there had been any change in size distribution resulting from the transport process (see Fig.4-3).

The fine material (<1mm) in the passive layer was not present when testing began, and therefore is assumed to have been produced by the grinding action of the sediment pump and the transport process. Sieve analysis of the active layer indicated a relatively small increase in the percentage of material finer than 1 mm presumably because most of this material settled quickly into the passive layer.

4.3.2 Grain-Size and Water Content Analyses of Bed-load Samples

A number of bed-load samples, taken with the basket and slice type samplers, described in Secion 3.4, were weighed wet and then dried to determine their water content. Table 4-3 lists the water contents for the various sampler types and flow conditions. The samples

were then sieved and an average grain size distribution was obtained for each of the sampler types and flow conditions. Figs. 4-4, 4-5 and 4-6 show the results of the sieve analyses.

TABLE 4-3 WATER CONTENT OF BED-LOAD SAMPLES

(1) Samples Taken During	(2) Method of Sampling	(3) Water Content of Sample % of Dry Weight
Flow Condition 1	Slice Sampler	6.2
	1.4 mm Mesh Basket	5.8
	2.4 mm Mesh Basket	7.1
Flow Condition 2	Slice Sampler	6.3
	1.4 mm Mesh Basket	4.6
	2.4 mm Mesh Basket	4.9
Flow Condition 3	Slice Sampler	7.1
	1.4 mm Mesh Basket	5.9
	2.4 mm Mesh Basket	7.4

Samples taken with the cart sampler were found to have an average water content of 9.2% of the dry sample weight. No attempt was made to sieve material caught by this sampler since it employed the same screen size and sampled the same flow as the slice sampler.

Observation of the slice sampler in operation indicated that it caught approximately 100% of the material greater than 1.41 mm but only a fraction of the smaller material. In computing total bed-load discharge (see Section 4.4), a correction of plus 8 percent was applied to slice sampler transport rates to account for this deficiency in the smaller sizes.

It can be seen from Figs. 4-4 to 4-6 that there is little difference in the size distributions of the material caught by the three bed-load samplers. This indicates that the basket-type samplers catch material which is representative of the fraction of the bed-load greater than 1.41 mm.

4.4 Bed-load Discharge Observations

The cart sampler and slice sampler were used to estimate the bed-load discharge for the cross-section average and flume centreline, respectively. Tables 4-4-A to 4-4-C give the sampling data obtained through the use of the cart sampler. Col. (1) of these tables is a six-digit identification number indicating the flow condition, sampler type, sample duration and the number of the sample within that particular sample set. Col. (3) is the sample catch weight after correction for moisture content. Col. (4) is the total dry transport rate in lb/min indicated

by that specific sample (i.e. Col. (3) divided by the sample duration in minutes). The average transport rate given at the bottom of the tables is the arithmetic average of the samples listed above it, without correction for fine-material deficiency.

Tables 4-5-A to 4-5-I give the data from slice sampling on the flume centreline. There are three tables for one flow condition, each containing 50 samples of one duration. The transport rates listed are not corrected for fine-material deficiency.

A summary of the average transport rates indicated by the slice and cart samplers, after correction for fine-material deficiency, is given in Table 4-6.

TABLE 4-6 SUMMARY OF AVERAGE TRANSPORT RATES

(1) Flow Condition	(2) Average Indicated Transport Rates	
	(a) Cross-sectional Average lb/(min-ft)	(b) Centreline lb/(min-ft)
1	6.59	6.76
2	1.85	2.12
3	10.62	11.23

The values of Col. (2a) were found by multiplying the average transport rates indicated by the cart sampler by 1.08. The average values of Col. (2b) are based on the 3 sets of slice samples each taken at

different durations, after corrections for fine-material deficiency.

4.5 Summary of Flow Condition Data

Table 4-7-A is a summary of the results given in Sections 4.1 to 4.4. All the columns of this table have been defined previously, with the exception of Col. (6) which is the median grain size diameter as determined from sieve analyses of samples taken with the slice sampler. The D_{50} of the slice sampler material was very close to that of the total bed-load as indicated in Section 4.3.

Table 4-7-B lists non-dimensional parameters which have been calculated from Table 4-7-A. Col. (2) is the depth to grain size ratio, found by dividing the values of Col. (3) Table 4-7-A by Col. (6) of the same table. Cols. (3a) and (3b) list values of Froude number, $\frac{V^2}{gh}$, calculated from the cross-sectional mean velocity and centreline mean velocity, respectively. Cols. (4a) and (4b) list values of densimetric Froude number, $\frac{\rho_f\ V^2}{\gamma_b'\ h}$ for the cross-sectional and centreline mean velocities, respectively. Cols. (5a) and (5b) are measured bed-load concentrations, $C = \frac{g_s\ b}{(Q\rho_f\ g)60}$ (cross-sectional average) and $C_{\mathcal{C}} = \frac{g_s}{(V_{\mathcal{C}} h\rho_f g)60}$ (centreline). These concentrations are expressed in parts per million by weight (ppm).

4.6 Basket-type Bed-load Sampler Observations and Results

Sampling with the basket-type bed-load sampler was carried out with three sampling durations for each of the three flow conditions, as indicated in Section 3.6. The results of the sampling with the 1.4 mm mesh basket are quoted in Tables 4-8-A to 4-8-I. Similarly, Tables 4-9-A to 4-9-I give the sampling results for the 2.4 mm mesh basket. These data are presented in the same format as the slice sampler data discussed in Section 4.4. Calculated transport rates and sampling efficiencies based on these data are given in Section 5.4.

In performing basket-type bed-load sampling, three phenomena were noted which could account for the low efficiencies reported in field studies (Hollingshead, 1968; Samide, 1971).

(1) Upon placing the sampler on the bed, some of the material approaching its mouth was deflected around the corners of the sampler as shown in Fig. 4-7-A.

(2) While observing the sampler from above, it was noted that some of the bed-load would slow down or stop completely in the region directly in front of the basket. This was very apparent when a dune approached the sampler mouth and became deformed as shown in Fig. 4-7-B.

(3) In the case of fairly large samples, a portion of the small material entering the sampler near the end of the sampling duration would roll up the face of the accumulated material and escape through the top screening, as indicated in Fig. 4-7-C.

Of these three observations the first two were probably the most important factors affecting the efficiency. It was also noted that as the volume of material in the sampler increased, the blocking effect also increased. This would indicate the advisability of sampling for relatively short durations. Sampling duration will be considered further in Section 5.5.

4.7 Bed-form Observations

All three flow conditions utilized in this study had low amplitude dune-type bed-forms associated with the progression of bed-load down the flume. Plates 4-2, 4-3 and 4-4 show upstream views of dune configurations produced by the first, second and third flow conditions respectively.

The first and third flow conditions produced dunes having a crescent shape. Each occupied 1/2 to 2/3 of the flume width and occurred alternately down the flume as shown in Fig. 4-8-A. The second flow

condition produced very low amplitude dunes which were more two-dimensional than those of first or third. They extended over the full width of the flume except for the regions close to the walls, where they were not discernable (see Fig. 4-8-B).

Four dune profiles were made with the bed sensing probe described in Section 3.3, for each of the three flow conditions. They revealed the bed-forms to be complex combinations of large and small dunes under all three flow conditions. It was immediately obvious that in order to draw any detailed quantitative conclusions concerning the development and size of these bed-forms, a large number of such plots should be taken. Owing to the limited amount of time available, this was not possible.

From the plots that were taken, ranges of dune heights and wave lengths observed at the sampling location were derived. This information is given in Cols. (3) and (4) of Table 4-10.

TABLE 4 - 10 DUNE SIZES AND CELERITIES

(1) Flow Condition No.	(2) Dune Height Range ft	(3) Dune Wavelength Range ft	(4) Average Dune Celerity ft/min
1	.09 - .15	4.0 - 10.2	1.47
2	.07 - .15	3.4 - 7.7	-
3	.12 - .18	3.2 - 14.3	1.43

Also given is an average dune celerity for flow conditions 1 and 3. This was obtained by measuring the amount of time necessary for the crest of a dune to travel a fixed distance and is the average of 20 such observations. In the second flow condition the dune crests were not easily detectable.

An interesting observation, noted from the dune profiles, was that dune height and wavelength appeared to increase in the downstream direction, for the moderate and high transport rates. At the low transport rate no such trend was apparent.

CHAPTER 5

ANALYSIS OF DATA

5.1 Calculations of Bed-load Discharge by Formulae

5.1.1 Calculations Based on the Formula of Meyer-Peter and Muller (1948)

The Meyer-Peter and Muller equation for a channel having negligible side resistance can be written in the form

$$0.25\, \rho_f^{1/3}\, g_s'^{\,2/3} = RS \left| \frac{K_b}{K_b'} \right|^{3/2} - .047\, \gamma_b'\, Dmn$$

R is the hydraulic radius and Dmn is the effective diameter of the sediment given by

$$Dmn = \Sigma_p\, D$$

where p is the fraction by weight of that fraction of the bed sediment with mean size D. The summation is taken for all fractions of the bed sediment.

The following is a list of the parameters which remained constant for the three flow conditions:

$\rho_f = 1.94 \text{ lb. sec.}^2/\text{ft.}^4$

$\gamma = 62.3 \text{ lb./ ft.}^3$

$\gamma_b' = (2.63 - 1.0)\ 62.4 = 102 \text{ lb./ft.}^3$

$K_b' = \dfrac{48}{D_{90}^{1/6}} = 68$ with D_{90} in feet

$D_{mn} = .018$ ft.

g_s' is the unit width transport rate in lb./(sec.-ft.)

K_b is the Strickler roughness coefficient for the entire bed including bed-forms while K_b' is the Strickler roughness coefficient due to the grains alone. K_b was found from the equation

$$K_b = \frac{1.49}{n} = \frac{V}{R^{2/3}\ S^{1/2}}$$

The values of D_{90} and D_{mn} were taken from the initial grain size distribution of the material used in the flume (see Fig. 3-1). The small decrease in grain size of the bed-load due to the grinding action of the pump, has been neglected for these calculations.

With the values of the parameters inserted, the equation becomes

$$0.312 \quad g_s'^{\,2/3} = 62.4\ RS\left(\frac{K_b}{K_b'}\right)^{3/2} - .086$$

The results of the calculations for the three flow conditions are given in Table 5-1. A bed-load discharge has been calculated for the cross-sectional average and for the centreline region assuming an infinite flume width (R = h). The bed-load discharges have also been given as concentrations to facilitate the comparison of results of the prediction techniques with the measured results.

5.1.2 Calculations Based on the Modified Einstein Method of Colby and Hubbell (1961)

The first step in the computation of bed-load discharge by the modified Einstein method was the solution of the equation

$$V = 32.6 \quad \sqrt{(RS)}_m \quad \log_{10} \quad 12.27\ \frac{xh}{k_s}$$

where x is a dimensionless parameter in the logarithmic velocity distribution law and k_s is the equivalent sand grain roughness diameter (all units given in pound-foot-second units).

The solution was carried out with the use of a graph (Plate 1, Colby and Hubbell, 1961). For this procedure k_s was taken equal to D_{65} of the initial grain size distribution of the material used in the flume (see Fig. 3-1). The dimensionless parameter x, determined from Plate 1 (Colby and Hubbell, 1961), was 1 in all cases. Values of $\frac{xh}{k_s}$ are given in column 4 of Table 5-2. From the values of $\frac{xh}{k_s}$ and Vm, values of $\sqrt{(RS)_m}$ are found from Plate 1.

Table 5-3 shows a sample of the remaining calculations for the centreline region of flow condition number 1. The grain size distribution was broken down into ranges and the geometrical mean diameter D (Col. 3) for each range was calculated. The dimensionless shear stress parameter Ψm was computed from the following relations depending on the relation of D to D_{35} for each size range

$$\Psi_m = (S.G._s - 1.0)\ \frac{D_{35}}{(RS)_m}\ (\text{for } D < 2.5\ D_{35})$$

$$\Psi_m = 0.4\ (S.G._s - 1.0)\ \frac{D}{(RS)_m}\ (\text{ for } D > 2.5\ D_{35})$$

where $S.G._s$ is the specific gravity of the bed material particles. The D_{35} was taken from

Fig. 3-1 to be 0.0102 ft. and therefore Ψ_m is calculated using the D_{35} size except for the two largest size ranges.

According to the modified Einstein relationship the intensity of bed-load transport is $\Phi_*/2$, if Φ_* is determined from the relationship between Φ_* and Ψ_* given by Einstein (1950) with Ψ_m substituted for Ψ_*. The bed-load discharge is then computed from the equation

$$g_s' = \Sigma p \tfrac{1}{2} \Phi_* \gamma_b \left(\frac{\gamma_b}{\gamma} - 1\right)^{\frac{1}{2}} (g D^3)^{\frac{1}{2}}$$

where γ_b is the unit weight of the sediment particles. The total bed-load discharge for each flow condition expressed as a concentration is given in Col. (12) of Table 5-2.

5.1.3 Calculations Based on the Diagram of Cooper (1970)

From the graph of $C_{bt} - \frac{h}{D_{50}} - \frac{\rho_f V^2}{\gamma_b' h}$ by Cooper (1970) (see Fig. 2-2), the concentrations of bed-load in ppm by weight were obtained. For the purposes of computation, an average $\frac{h}{D_{50}}$ of 40 was used for the three flow conditions. Col. (3) of Table 5-4 gives the values of densimetric Froude number for the cross-sectional average and centreline for each of the three flow

conditions. Col. (4) lists the concentrations of bed-load in ppm as computed from Fig. 2-2.

TABLE 5-4 TRANSPORT RATES COMPUTED FROM COOPER'S (1970) DIAGRAM

(1) Flow Conditions No.	(2) Region	(3) $\frac{\rho_f V^2}{\gamma_b' h}$	(4) C ppm
1	x-sect average	.22	20
	centreline	.37	740
2	x-sect average	.21	10
	centreline	.26	160
3	x-sect average	.34	560
	centreline	.44	1200

5.2 Comparison of Results and Calculated Values of Bed-load Discharge Concentration

The results of the calculations found in Sections 5.1.1 to 5.1.3 are presented as logarithmic plots of $\frac{\rho_f V^2}{\gamma_b' h}$ versus C in Figs. 5-1-A and 5-1-B. Results for the cross-sectional average are given in the first figure while the results for the centreline are given in the second.

It can be seen from Fig. 5-1-A that the three bed-load calculation techniques predicted transport rates that were less than the measured values, with the

Meyer-Peter and Muller equation coming the closest. The modified Einstein method and graphical method of Cooper predicted results which were fairly close. For the centreline Fig. 5-1-B indicates that all three techniques gave results which were very close to the measured values. Again the graphical method of Cooper and modified Einstein method predicted similar results. The Meyer-Peter and Muller equation predicts rates which are higher than the other two.

5.3 Analysis of the Variability of Transport Rate

Figs. 5-2-A to 5-2-I show histograms and cumulative frequency diagrams for the sampling carried out on the third flow condition. Due to space limitations the figures for the first and second flow conditions were not included. These figures can easily be obtained from the data given in Tables 4-5, 4-8 and 4-9.

As the first step in analyzing the transport rate data, a check was made to determine if the variation of transport rate with time followed any of the simple distributions. This was done by plotting the logarithm and the square root of the unit width transport rate, as indicated by the slice sampler, on normal probability paper. The data gave a fairly good fit to a straight line on the square root probability graphs (see Figs. 5-3-A to 5-3-I). This would indicate that the square

root of the unit width transport rate is normally distributed with time.

Some of the characteristics of the distribution of unit width transport rate at a point are given in Table 5-5. Col. (3) is the mean transport rate, Col. (4) is the standard deviation of the sample, Col. (5) is the coefficients of variation, Col. (6) is the median value of transport rate and Col. (7) is the range of transport rates encountered in the sample.

A distribution which has the square root of its variate normally distributed exhibits a positive skew when plotted on an arithmetic scale. With such a skewed distribution the results of the sampling may have been affected by the length of the sample duration. A comparison of mean test was used to determine if duration had significantly affected the sample means. Col. (3) of Table 5-5 lists the mean values of transport rate that were tested.

Before making the comparison of means test, the variance of these sample means had to be examined. The standard deviations, given in Col. (4) of Table 5-5, decreased as the sampling durations increased for each of the three flow conditions. Physically this decrease in variance is indicative of the fact that the longer durations tend to average out the peaks and troughs in the transport rate fluctuations. The longer

durations will generally produce sampling distributions which have a smaller range and variance than those of shorter duration at the same mean transport rate (see Cols. (4) and (7) of Table 5-5).

Since the variance was found to be a function of the sampling duration the type of test selected to determine if the sample means differed significantly from one another was the test of means with nonhomogeneous variances (Neville and Kennedy, 1966, P150). Table 5-6 shows the data and result of this test. Cols. (2) through (9) are the duration, mean value, standard deviation and degrees of freedom of the two sample means being compared. Col. (10) is the angle θ determined by the formula $\tan \theta = \frac{S_{\bar{x}_1}}{S_{\bar{x}_2}}$. The calculated value of d, given in column (11) is determined from the equation $d = \frac{\bar{x}_1 - \bar{x}_2}{S^2_{\bar{x}_1} + S^2_{\bar{x}_2}}$. Col. (12) is the approximate value of d needed to reject the null hypothesis. The null hypothesis being tested in this case was: "There is no significant difference in the sample means being tested". Cols. (11) and (12) indicate that the null hypothesis was accepted in every case. On the basis of this comparison of means test, the three sample means were averaged to give one

mean transport rate for each flow condition. Table 5-7 lists these mean values.

TABLE 5-7 SLICE SAMPLER MEAN TRANSPORT RATES

(1)	(2) Flow Condition #1	(3) Flow Condition #2	(4) Flow Condition #3
Sample Means lb/(min-ft)	6.23 6.38 6.18	2.10 1.89 1.90	9.83 11.65 9.71
Final Mean	6.26	1.96	10.40

5.4 Average Transport Rate-Efficiency Relations

Basket sampling efficiencies were computed by comparing the average indicated transport rates of the samplers (see bottom of Tables 4-8 and 4-9) with those of the slice sampler (see Table 5-7) for each flow condition. Table 5-8 gives the results of the calculations of sampling efficienty. Col. (2) lists the average transport rates indicated by the slice sampler. Col. (5) gives the transport rates indicated by the basket samplers for each of the durations shown. Col. (6) is the sampling efficiency found by dividing the values of Col. (5) by the average transport rate for that flow condition (Col. 2).

The values of Table 5-8 suggest that efficiency increases with transport rate. If this is the case there

should be systematic variations between the transport rate distributions produced by the slice and basket samplers. To check if this was true the basket sampler distributions were compared to the slice sampler distributions. A comparison was done using the cumulative frequency data of the two sampler types for the same duration.

Sampling efficiencies were computed by taking the ratio of the transport rate indicated by the basket sampler to that of the slice sampler for the same cumulative frequency. The upper and lower twenty percent of the distributions were not compared because these regions were too sensitive to individual observations.

Efficiences computed from this comparison of distributions were plotted against the corresponding slice sampler transport rates. To make these plots easier to understand the data was separated into three groups depending upon whether the sampling duration was the shortest, intermediate or longest for that flow condition. Figs. 5-4 and 5-5 are these plots for the 1.4 mm and 2.4 mm mesh baskets. Also shown on these graphs are the transport rate-efficiency values obtained using an average transport rate for each flow condition.

5.5 <u>Effect of Sampler Fullness on Efficiency</u>

Table 5-9 lists the change in efficiency with

increasing sample duration for the two basket mesh sizes tested. Cols. (3a) and (4a) give the average dry sampler catch for each of the durations. Cols. (3b) and (4b) give the change in efficiency from that of the shortest duration computed from Table 5-8. The results are inconclusive for the first two flow conditions. There are some efficiency changes however these are not significant when compared to possible transport variations.

The third flow condition shows a definite decrease in efficiency as the sampler catch increases. From this it would appear that sampler overfilling has the greatest effect on high transport rate conditions. To verify this more sampling would be needed. A rough guide to keep the effect of this overfilling to a minimum would be to adjust the duration so that the sample volume for 90 percent of the samples is not greater than 1/3 to 1/2 of the total sampler volume.

5.6 Variation of Sample Means with Sample Size

The transport data was examined in an effort to determine the effect of varying the sample size on the sample mean. As indicated in Tables 4-5, 4-8 and 4-9, 50 samples were collected and averaged to arrive at the sample mean used in computing the efficiencies. In order to determine if this was an unnecessarily

large sample size, sample means using all possible consecutive combinations of 1, 2, 3 ..... 47, 48 and 49 samples were computed. These were then compared to the sample mean using 50 samples.

Fig. 5-6 is a plot of the percentage deviation of the mean transport rate using n samples from the mean using 50 samples against sample size n for the 1.4 mm basket sampler. The data for all three flow conditions was combined on the basis of the sampling duration being the longest, intermediate or shortest used for that flow condition. After approximately 20 samples there was no difference of the curves for the various durations. The decrease in deviation for sample sizes larger than 20 is probably due to the use of the 50 sample mean instead of the population mean which was not known. A sample mean based on a size of 20-25 samples would give a good estimate of the true mean.

For fewer than 20 samples the curves indicate that the deviation was less for longer durations. This difference was fairly small and was probably offset by the decrease in efficiency as the sampling duration increased. This decrease in deviation was to be expected since the variance of the indicated transport rate distribution will decrease with increasing duration, as discussed in Section 5.3.

Analysis of the 2.4 mm mesh basket and slice sampler data gave results which were similar to those of the 1.4 mm mesh basket.

5.7 Scaling Up of Model Sampler Efficiencies

The model sampler transport data was scaled up by the factor determined in Section 3.1.1. Table 5-10 lists the sampling results for both the model and prototype samplers. Col. (3) gives the model transport rates which were listed in Table 5-7. Col. (4) lists the equivalent prototype transport rates found by multiplying the values of Col. (3) by the transport rate per unit width scale of $5\sqrt{5}$. Col. (7) gives the efficiencies associated with these transport rates. Fig. 5-7-A is a plot of sampling efficiency against unit width transport rate for the two model basket sizes tested. Fig. 5-7-B is a similar plot for the prototype sampler values.

When sampling in the field, neither the actual transport rate nor the sampling efficiency are known beforehand, so that Fig. 5-7-B would necessitate an iterative type solution. This was avoided by defining a sampler "catch rate", C_r, which was found by dividing the average dry sampler catch by the duration. Col. (5) of Table 5-10 lists the sampler catch rates determined from the sampler models. Col. (6) is the prototype

sampler catch rates found by multiplying the values of Col. (5) by the catch rate scale of $25\sqrt{5}$. Fig. 5-8-A shows a plot of sampler catch rate against unit width transport rate for the two model basket sizes tested. Fig. 5-8-B is a similar plot for the prototype sampler values. This plot does not require an iterative solution.

In field sampling a catch rate can be obtained by taking the estimated dry weight of each sample and dividing it by the sampling duration. Entering the ordinate of Fig. 5-8-B with this value, the dry unit width transport rate can be read off the abscissa. The distribution of transport rate with time for a field situation could be estimated using this procedure.

It should be noted that Fig. 5-8-B only applies to the 30 in. x 24 in. x 10 in. basket sampler with either a 1/4 inch or 1/2 in. mesh basket. An application of this figure to field data will be given in Section 5.9.

5.8 Suggested Field Sampling Procedure

1. All samples taken at one section for one flow condition should be of the same duration and have approximately the same period between them.

2. Begin with a sampling duration which is thought to produce maximum sample volumes of from 1/3 to 1/2 of the total sampler volume.

3. After a number of samples have been taken check to ensure that the sampler is not being over-filled by more than 10 to 15 percent of the samples. If this is the case, decrease the sampling duration.

4. If the sampler is catching very small amounts of bed-load, increase the sampling duration so that an average catch would occupy 1/5 to 1/4 of the sampler.

5. Collect as many samples at each section as variability of discharge and time will permit. If possible 20 samples should be taken at each sampling location.

6. Take each sample catch and divide by the sampling duration to arrive at a catch rate for wet bed-load.

7. Correct this value for moisture content to arrive at a catch rate of dry bed-load.

8. Enter Fig. 5-8-B with this catch rate and from the curve for the particular basket type determine the average dry transport rate for that sample.

5.9 Application of Prototype Efficiencies to Field Data

To test the results of the laboratory modelling, sample data compiled by Hollingshead (1971) from the

studies of the Elbow River were re-calculated using Fig. 5-8-B instead of assuming a constant sampling efficiency of 45 percent. Cols. (1) to (4) of Table 5-11 repeats some of the data for the Elbow River as given in Table 1 of Hollingshead (1971). The catch rates (Col. 5) were obtained by taking the indicated bed-load discharge as given in Table 1 and reducing it to the average catch for a 2 foot wide 1/4 inch mesh basket sampler. The values of Col. (6) were computed from the curve for the 1/4 inch mesh basket of Fig. 5-8-B. The estimated coarse material bed-load (Col. 7) was obtained by multiplying the values of Col. (6) by the width of the bed movement. Values of total bed-load were obtained by dividing the values of Col. (7) by 0.7 (suggested by Hollingshead) to account for fine material deficiency.

Fig. 5-9 plots the re-calculated total bed-load discharges against fluid discharges and compares these with the curves obtained by Hollingshead from estimates of pit refilling for 1968 and 1969. The agreement appears to be very good, indicating that the laboratory modelling produced reasonable results.

Some of the transport data collected on the Elbow River (Samide, 1971) was scaled down to obtain transport rate distributions with which the laboratory results could be compared. Two Elbow River discharge ranges were examined with approximately 25 basket

samples collected in each range. Fig. 5-8 was used to predict prototype transport rates from the basket samples. The distributions obtained were then scaled down and compared to laboratory data.

Fig. 5-10 gives the cumulative frequency plots for the field and laboratory data. From this it can be seen that the general shapes and ranges of the distributions are approximately the same even though the mean rates differ somewhat. The flume transport rate distributions appear to be true scale models of the distributions encountered in field sampling.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The observations of Section 4.6 and results of Chapter 5 lead to the following conclusions concerning the behaviour of basket-type bed-load samplers:

1. The constant sampling efficiency of 45% formerly used for most basket-type bed-load samplers, appears to be too large for all but the highest transport rate tested.

2. The sampling efficiency for the two sizes of basket mesh tested, decreases as bed-load discharge decreases.

3. The bed-load samplers appear to catch material which is characteristic in grain size of the actual bed-load greater than 1.41 mm.

4. The sampling should be of a duration such that no more than 10% of all samples have a volume greater than 1/2 of the total sampler volume.

5. It is necessary to collect approximately 20 samples to arrive at a good estimate of mean bed-load discharge. For fewer than 20 samples the reliability of the sample mean drops fairly rapidly with sample size.

6. Scour at the corners of the sampler causing the material to deflect around the edges and the decrease in flow velocity at the sampler entrance are probably the two main reasons for the low sampling efficiencies reported in the study.

7. The application of model results to field data indicates that the Froude modelling was satisfactory.

The application of the bed-load prediction techniques to the flow data obtained in this study leads to the following conclusions:

1. The bed-load prediction techniques when applied to the flume centreline data produce better results than when applied to average cross-sectional data.

2. The three techniques tested, indicate centre-line transport rates which fall within a factor of 3 of the measured rates.

Several conclusions concerning the nature of bed-load transport in general can be made:

1. The sampling methods employed in this study were very time consuming and laborious. An automatic sampling or continuous recording

apparatus would be of great benefit in future flume studies.

2. An analysis of sampling data indicates that the distribution of transport rate with time is square root normally distributed.

3. Dune-type bed-forms found in this gravel transport study were of two distinct patterns although the flow was subcritical for all conditions.

4. There appears to be an entrance length associated with the development of dune heights and wavelengths in a flume.

6.2 Recommendations

The following recommendations can be made from the results of this study:

1. Consideration could be given to determining the effect on sampling efficiency of other depths of flow.

2. Very low transport rates could be investigated to determine conditions under which the sampling efficiency will become zero.

3. The basket-type bed-load sampler, used in gravel rivers can give reasonable results, however,

care should be taken in the selection of durations and procedures to carry out the sampling.

4. The development of a reliable automatic sampling system or continuous bed-load discharge recording apparatus would be of great benefit in future flume studies.

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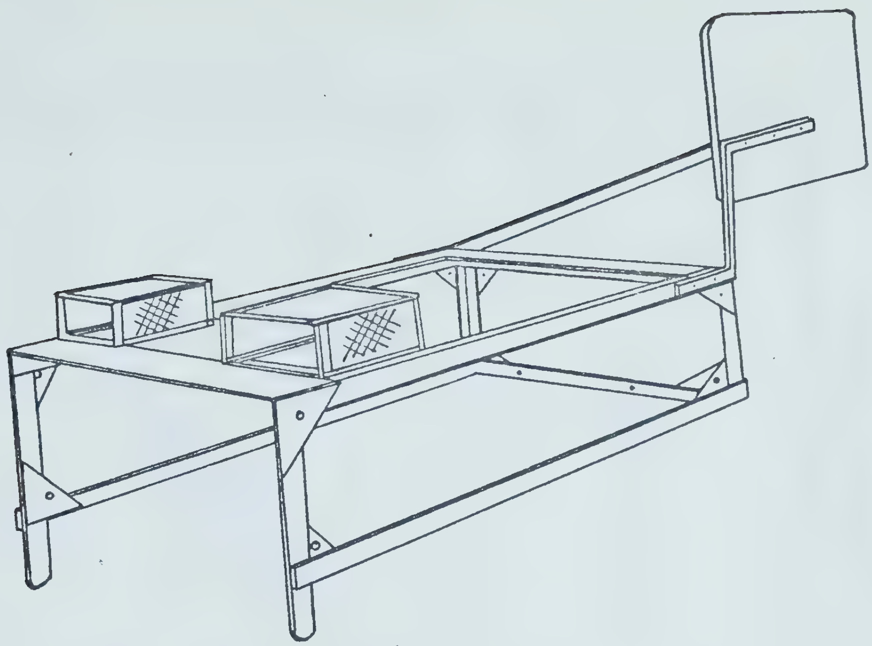
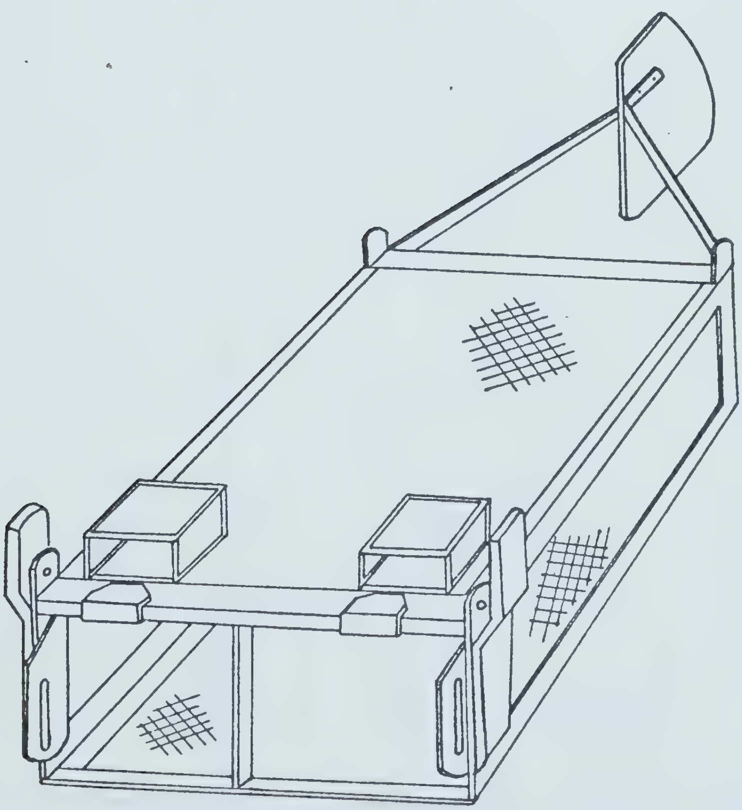
Shteynman, B.S., "Certain Patterns in the Movement of Streambed Sediments", Soviet Hydrology, No. UDC 551.482.212.3, American Geophysical Union, Washington, 1966, pp. 650-653.

Yalin, M.S., "Similarity in Sediment Transport by Currents", Hydraulic Research Paper No. 6, Hydraulic Research Station, Wallingford, England, 1965.

APPENDIX A - FIGURES



A- EHRENBERGER SAMPLER FRAME



B- NESPER SAMPLER

FIG.2-1 EARLY BASKET SAMPLERS FROM HUBBELL, 1964

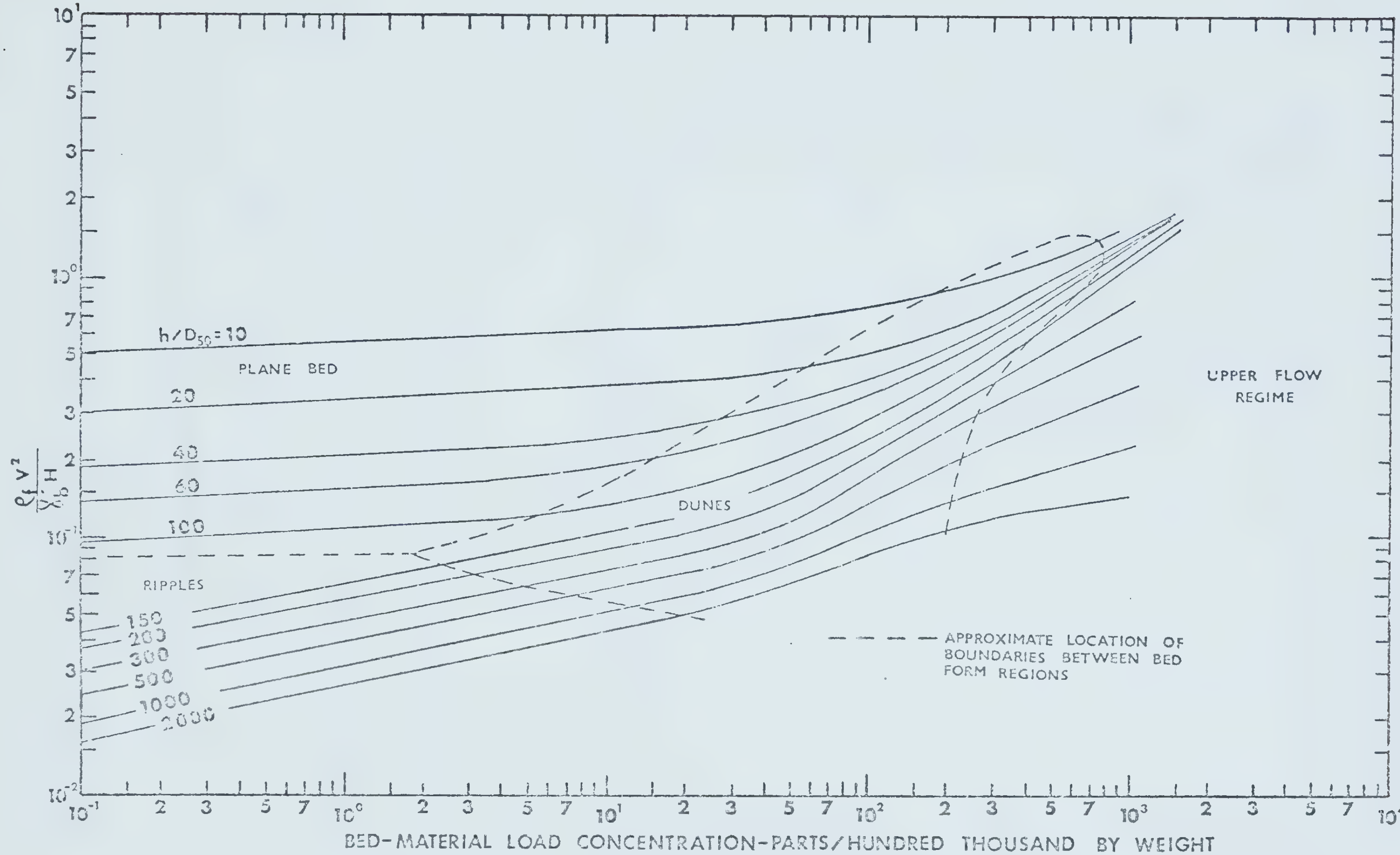
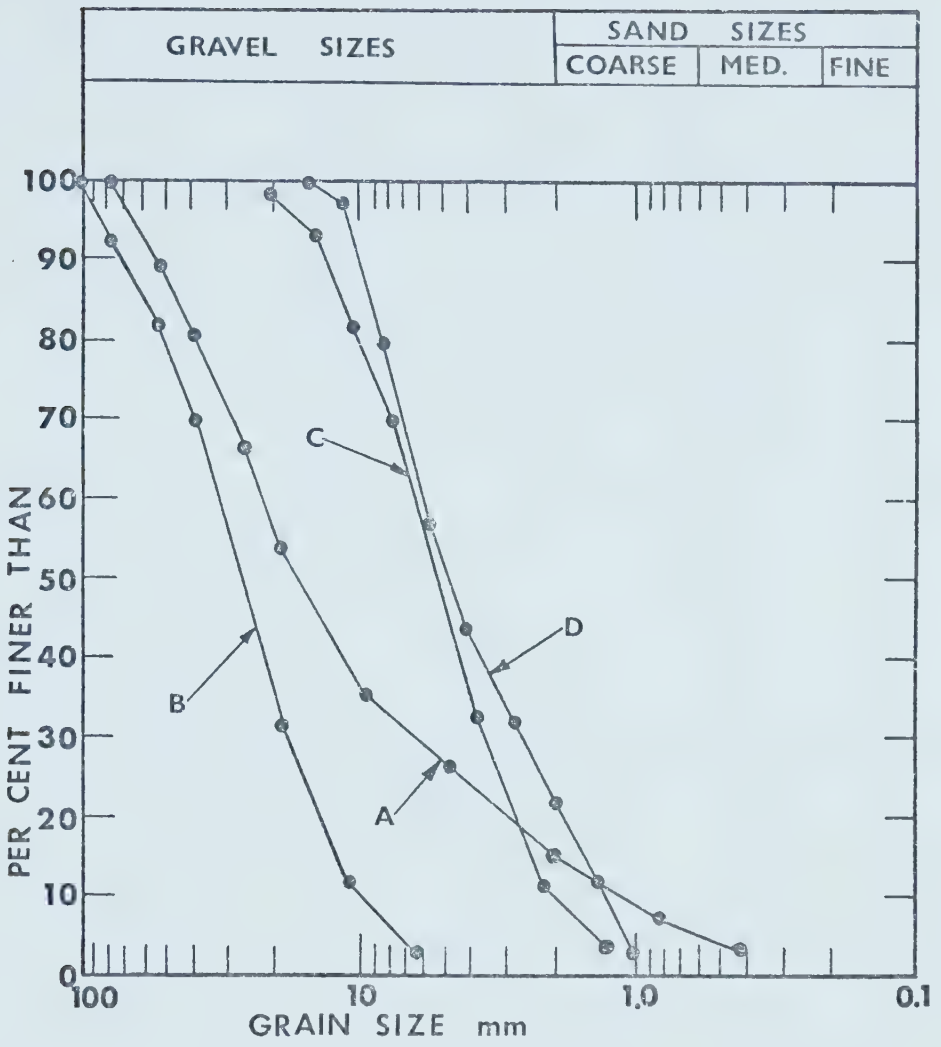


FIG. 2-2 FLUME TRANSPORT DIAGRAM FROM COOPER, 1970



A–BED–LOAD, 1968 EXCAVATION DEPOSITS– ELBOW RIVER

B – BED–LOAD, FIELD BASKET SAMPLES – ELBOW RIVER

C – TRUE SCALE–MODEL BED – MATERIAL

D – AVAILABLE FLUME BED – MATERIAL

FIG. 3-1 GRAIN SIZE DISTRIBUTION MODELLING

4.3-2-6 BASKET SAMPLER

PART	NAME
1	SAMPLER FRAME
2	LOCKING SCREWS
3	SAMPLER TAIL
4-6	TAIL BOLTS
7	1.4 MM BASKET
8	2.4 MM BASKET

DIMENSIONS IN INCHES

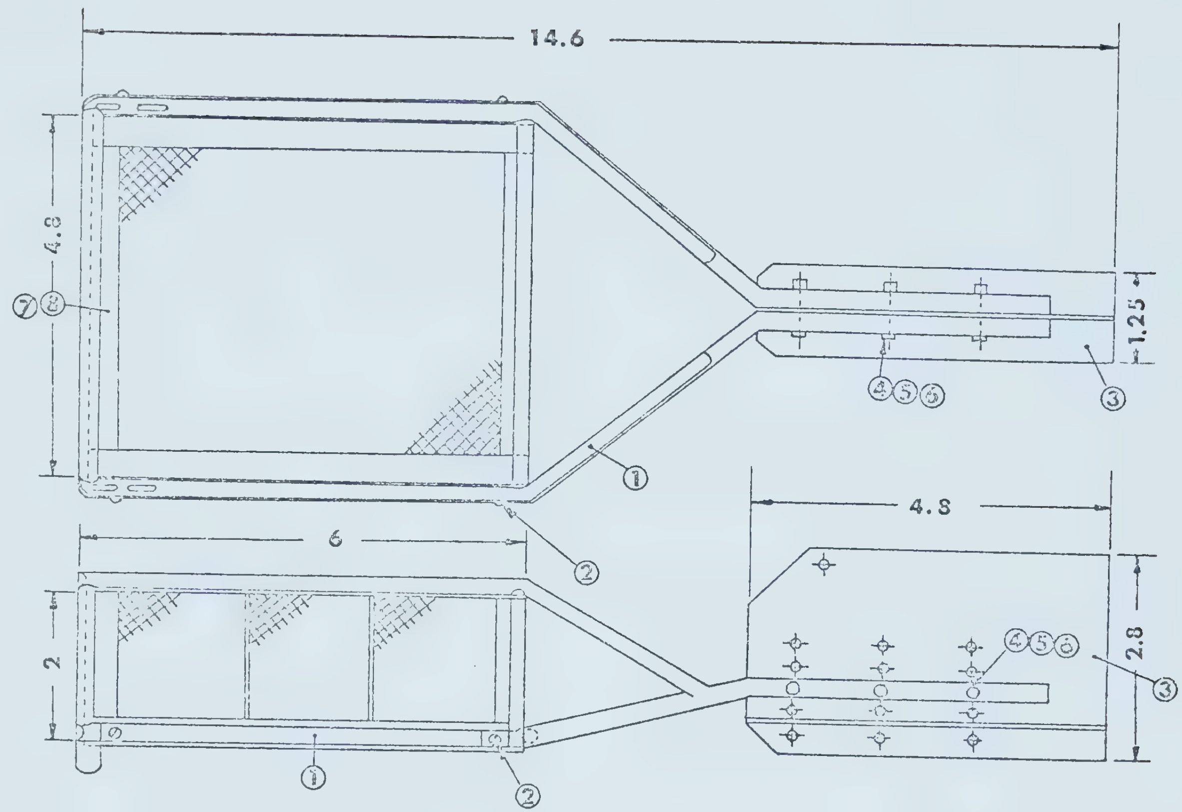


FIG. 3-2 PLAN AND ELEVATION-MODEL BASKET BED-LOAD SAMPLER

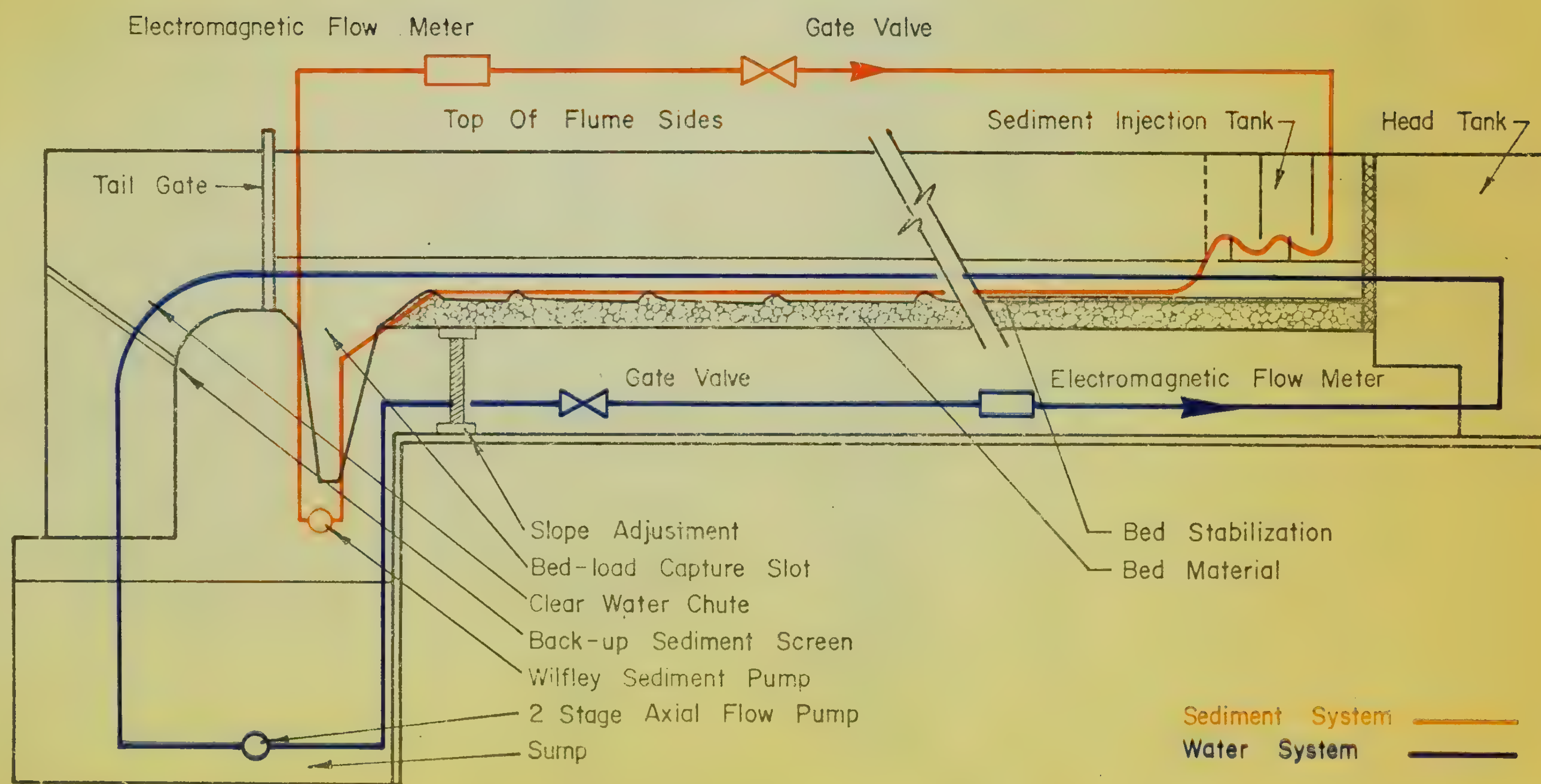


FIG. 3-3 SIMPLIFIED DIAGRAM OF FLUME SET-UP

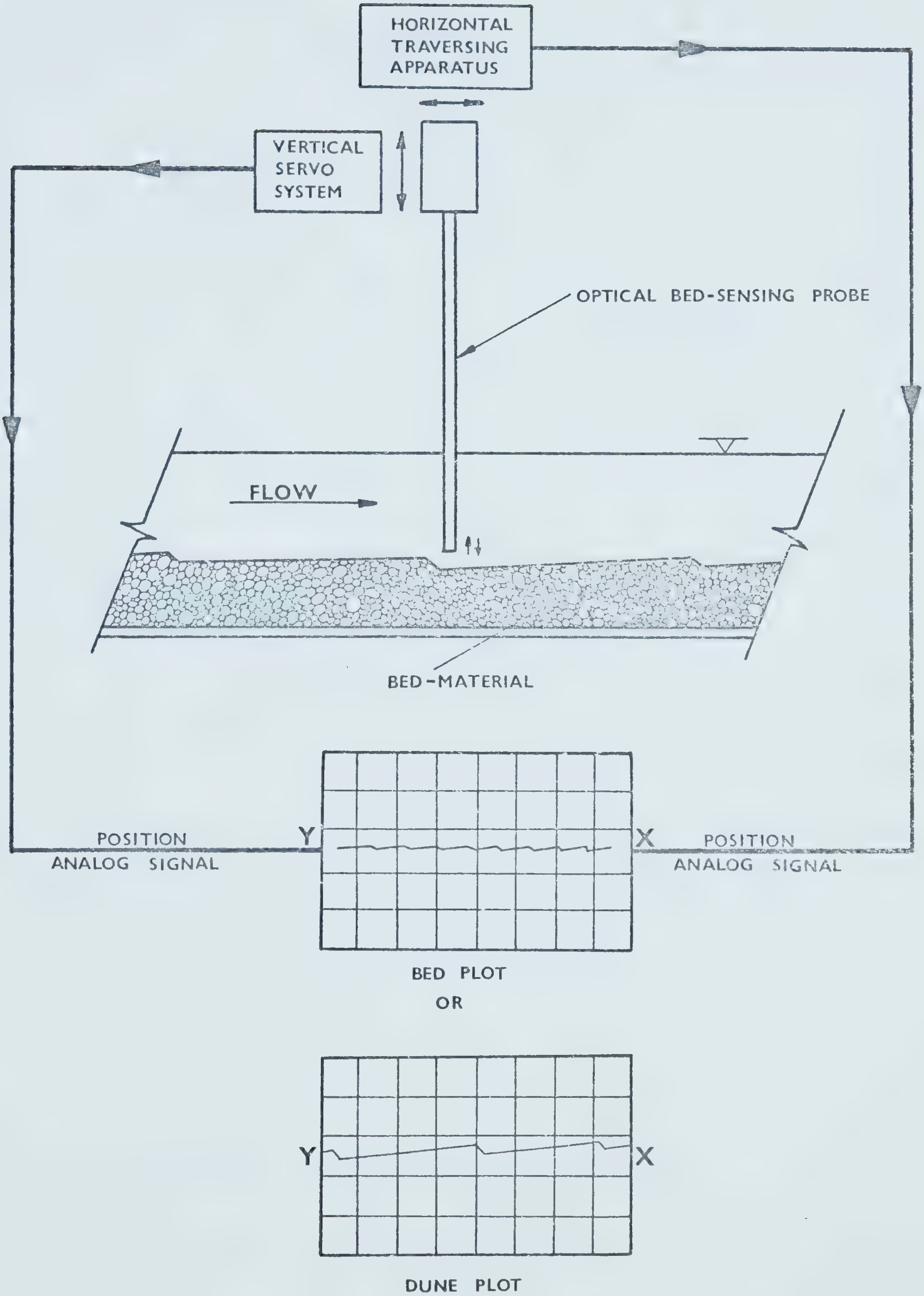


FIG. 3-4 SIMPLIFIED OPTICAL BED SENSING PROBE

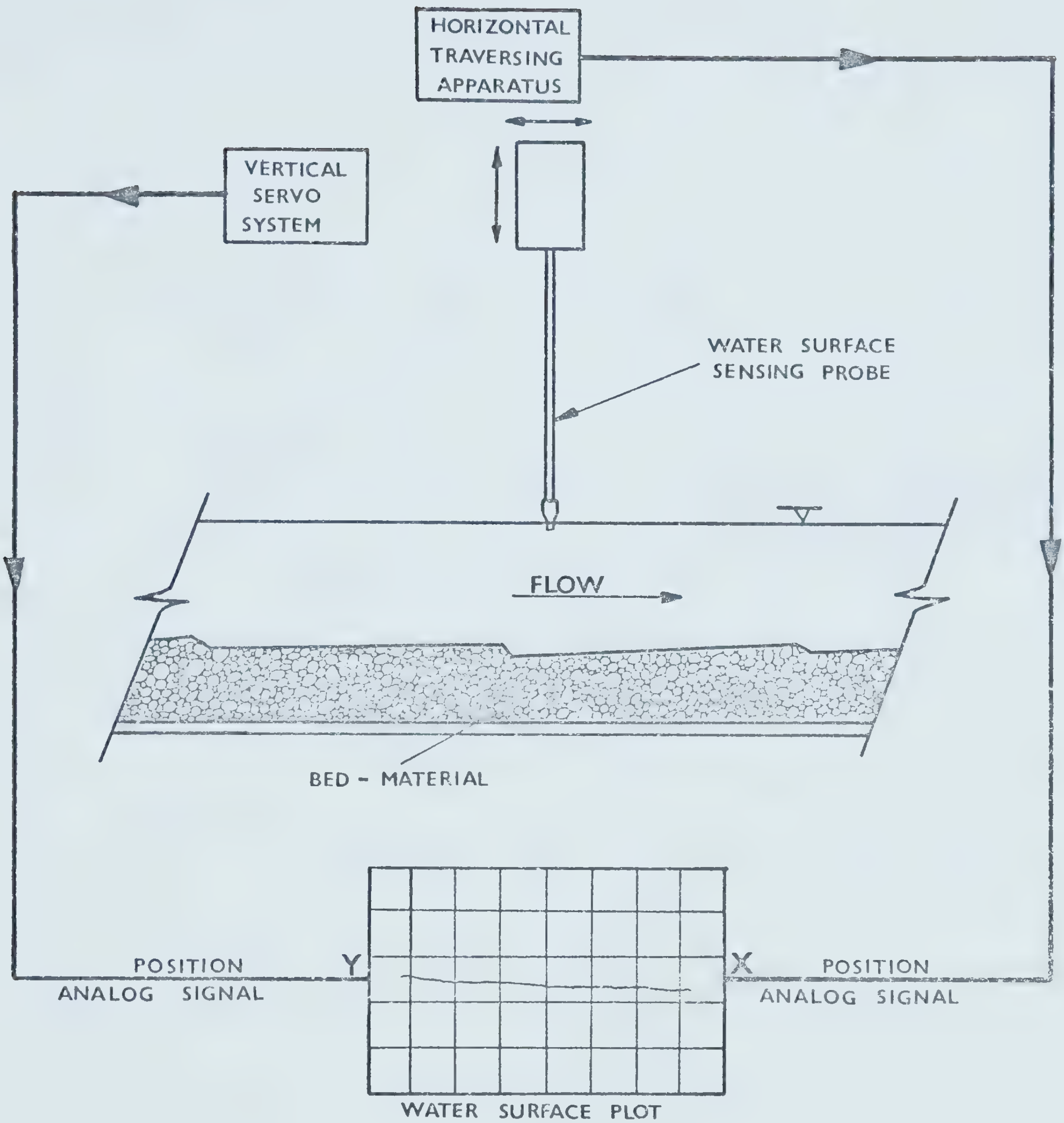


FIG.3-5 SIMPLIFIED WATER SURFACE SENSING PROBE

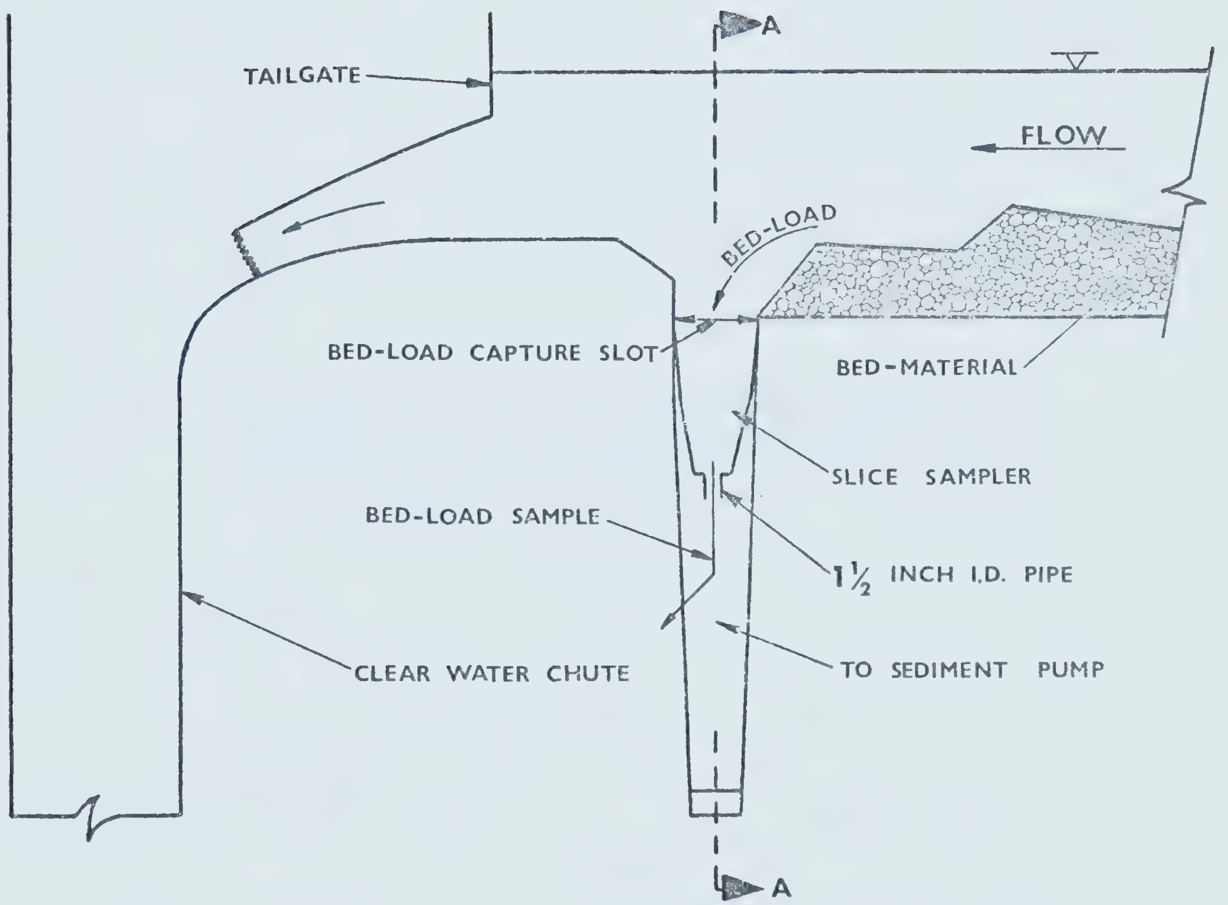
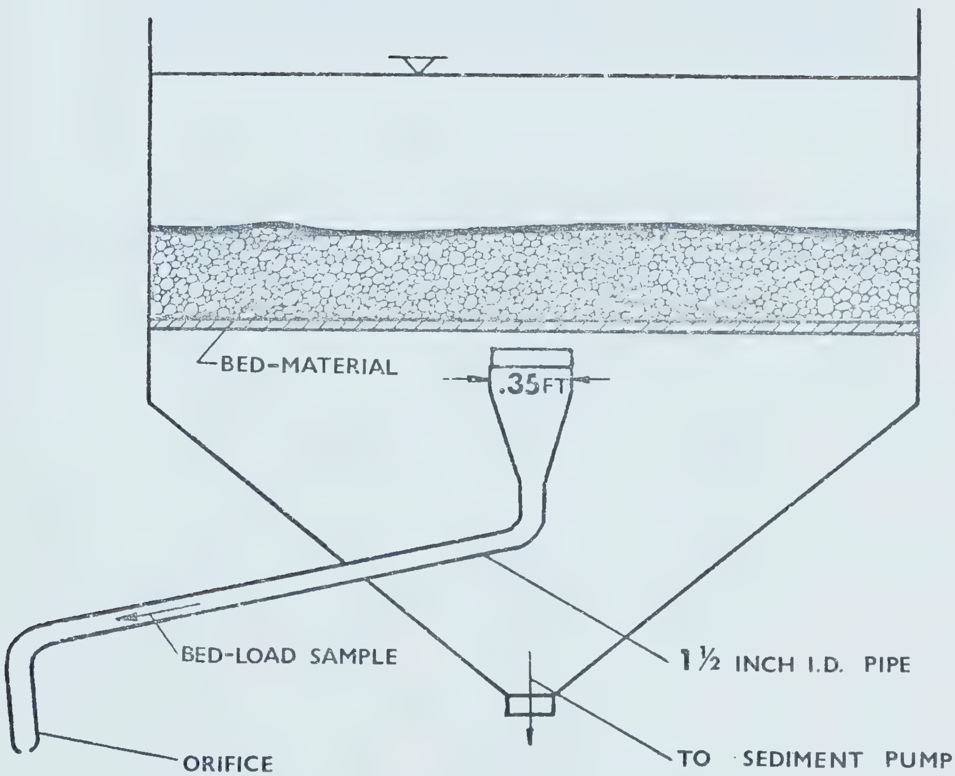


FIG. 3-6-A LONGITUDINAL PROFILE ALONG FLUME CENTRELINE AT DOWNSTREAM END



SECTION A-A

FIG. 3-6-B SECTION THROUGH BED-LOAD SLOT SHOWING SLICE SAMPLER

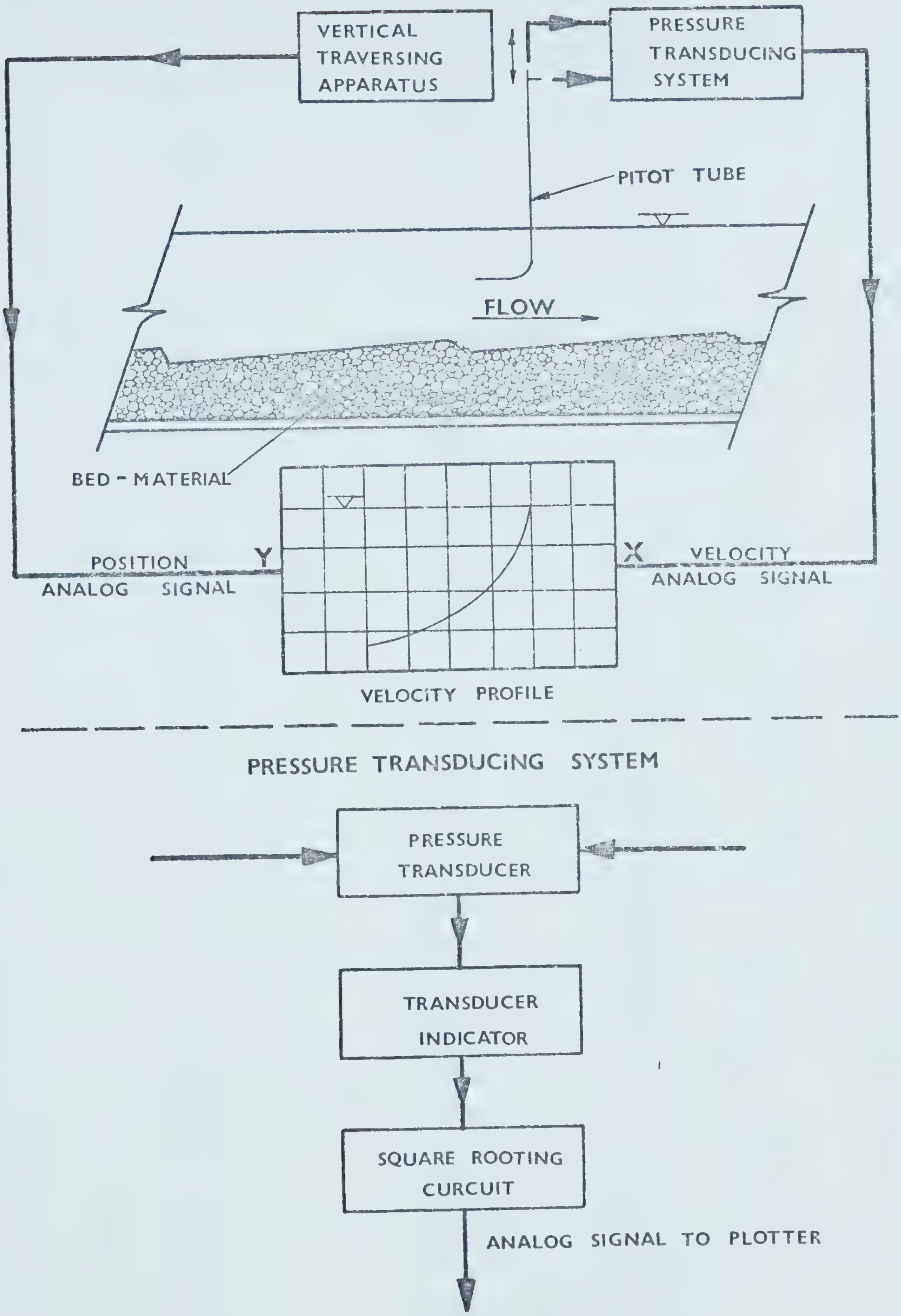
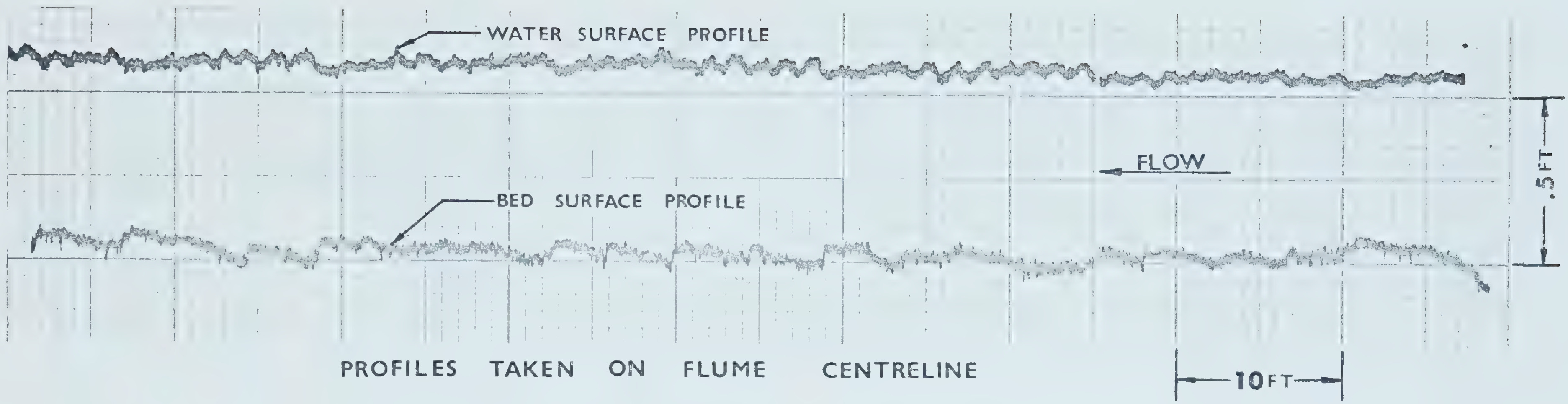
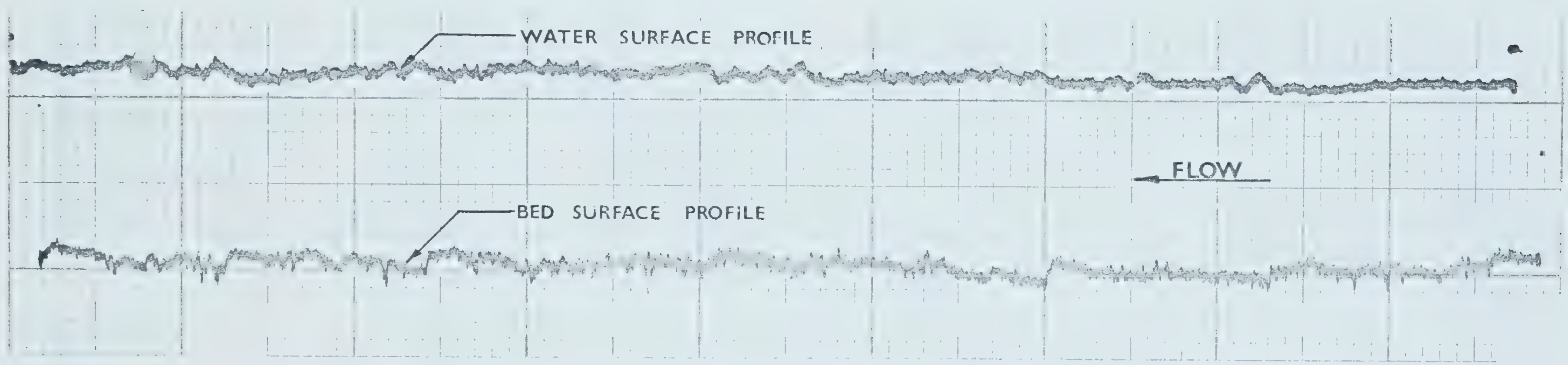


FIG. 3-7 SIMPLIFIED VELOCITY PROBE



PROFILES TAKEN ON FLUME CENTRELINE



PROFILES TAKEN 1 FT. LEFT OF FLUME CENTRELINE
FLOW CONDITION NO. 2

FIG. 4-1 TYPICAL BED AND WATER SURFACE PROFILES

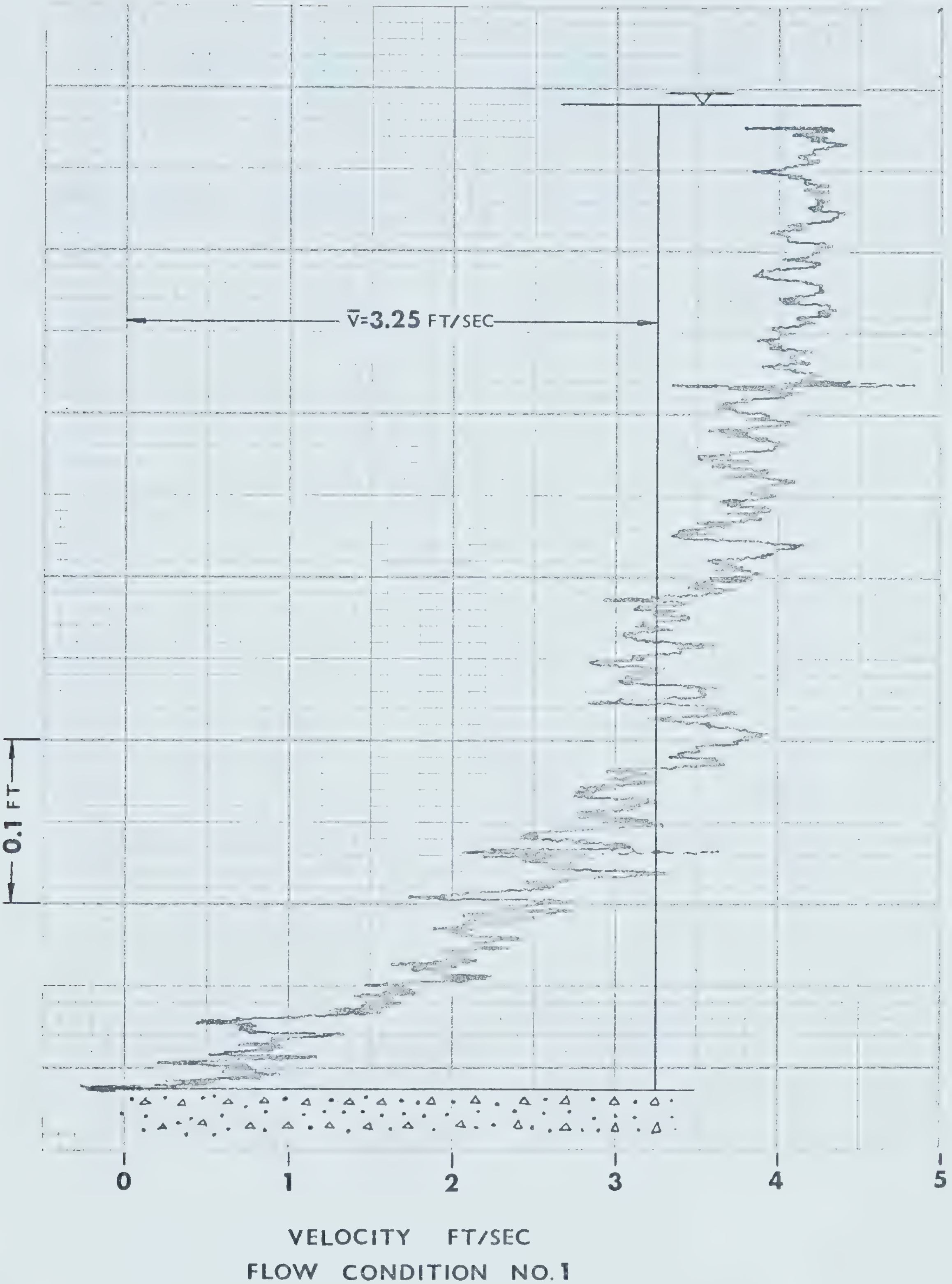
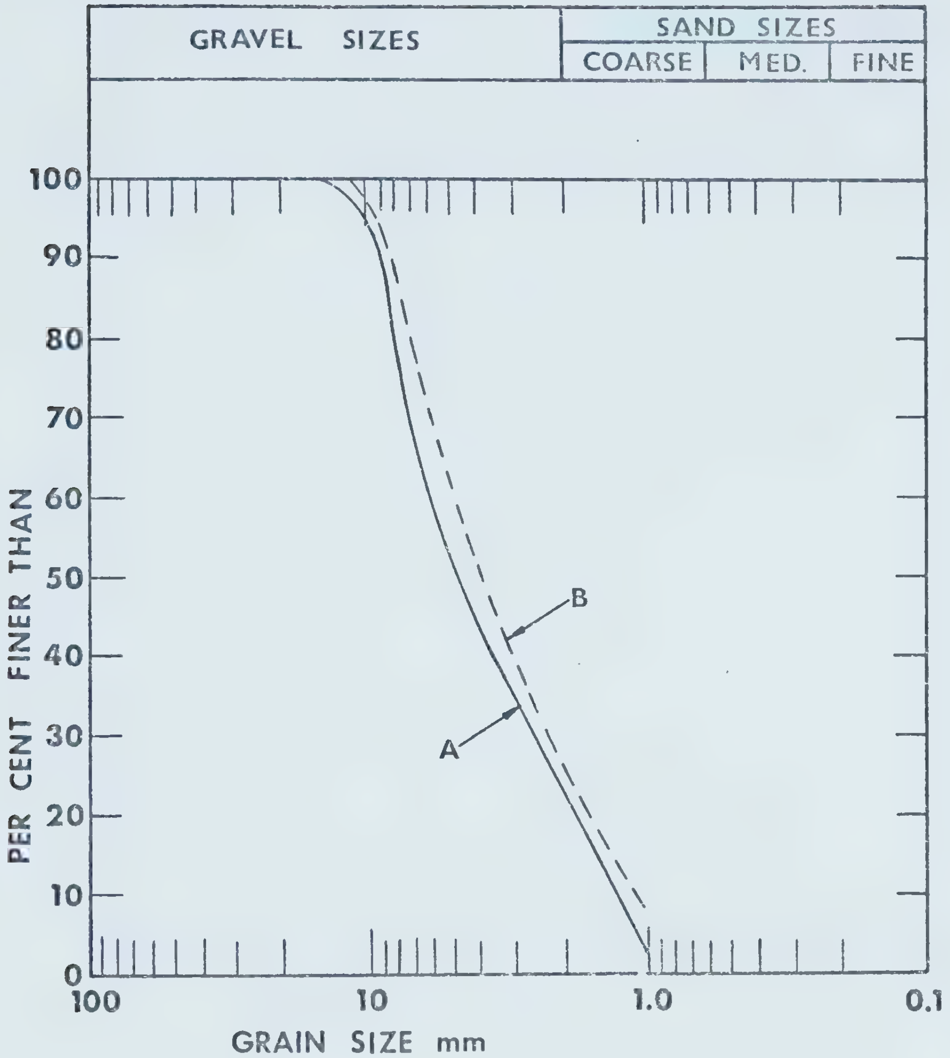


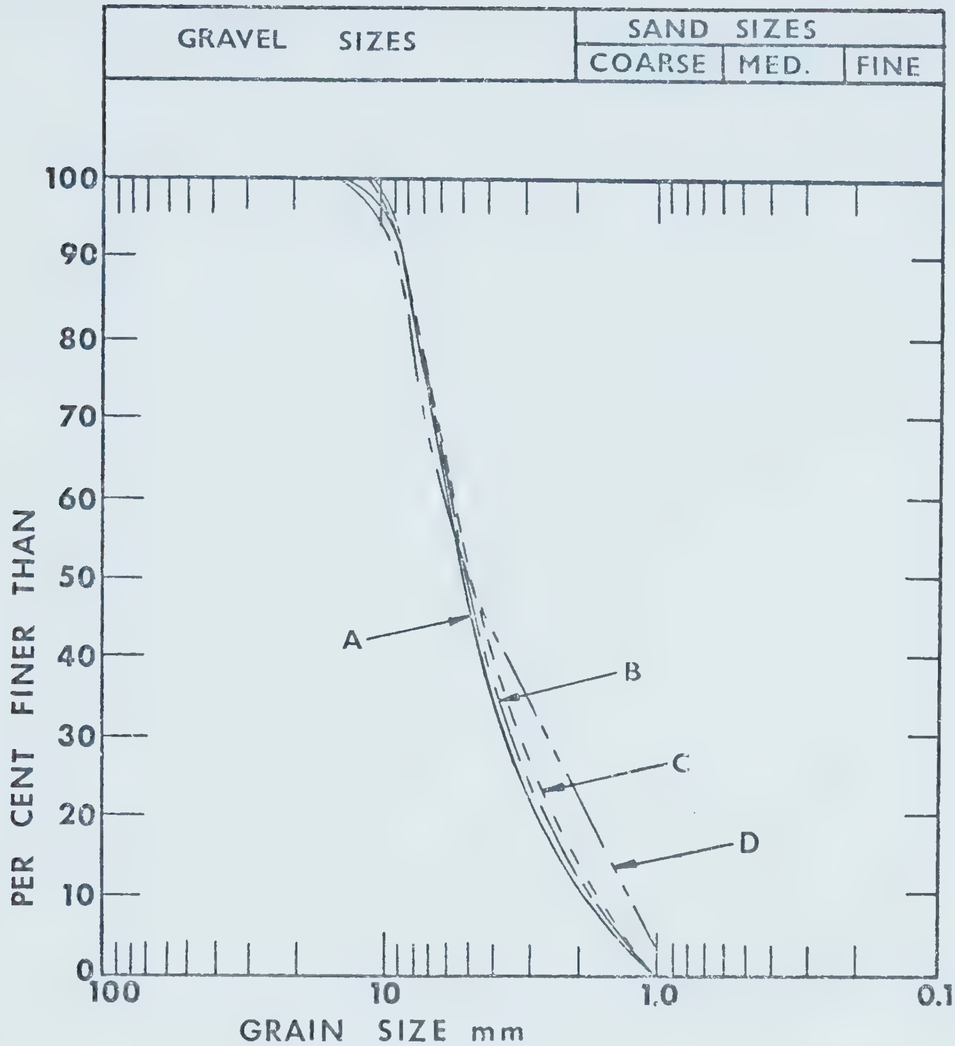
FIG.4-2 TYPICAL CENTRELINE VELOCITY PROFILE



A- VOLUMETRIC SAMPLES OF BED-MATERIAL
(BEFORE TESTING)

B- VOLUMETRIC SAMPLES OF BED-MATERIAL
(AFTER TESTING)

FIG. 4–3 GRAIN SIZE ANALYSES FOR BED-MATERIAL
BEFORE AND AFTER TESTING



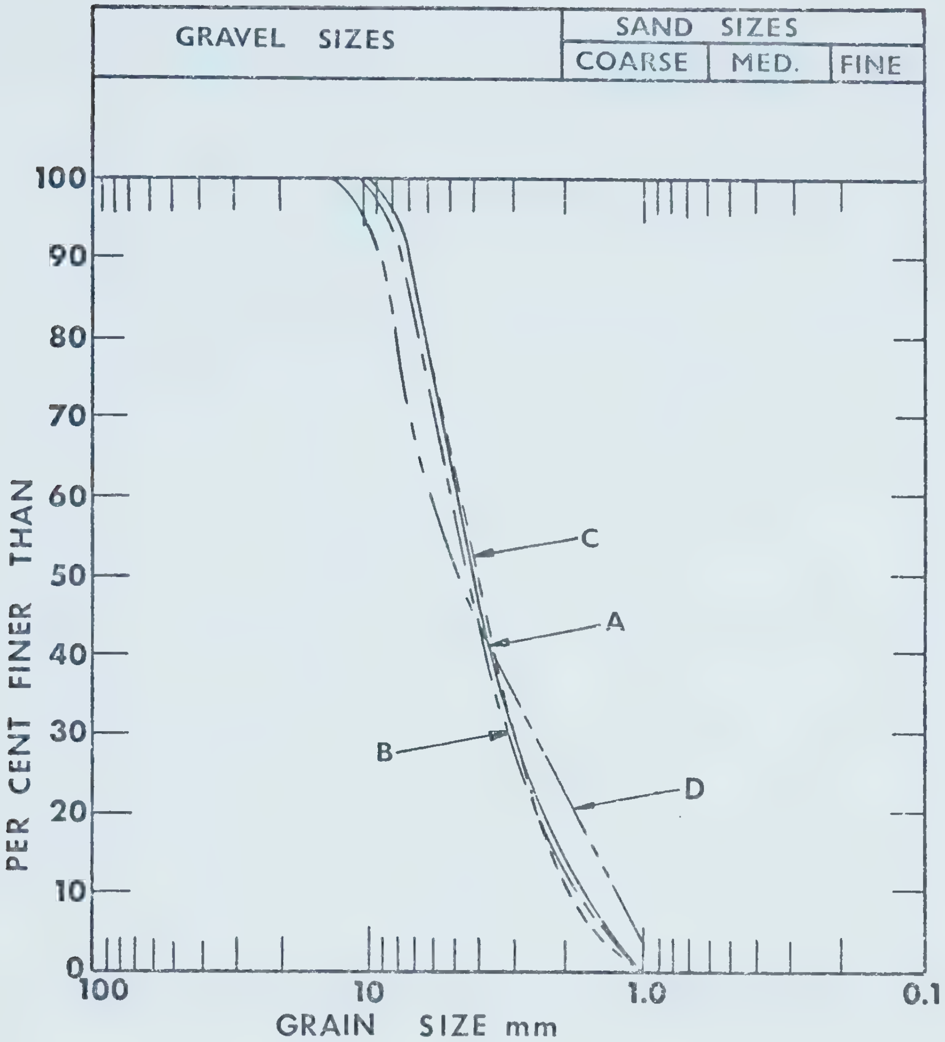
A – SLICE SAMPLER SIEVE CURVE

B – 2.4 mm MESH BASKET SIEVE CURVE

C – 1.4 mm MESH BASKET SIEVE CURVE

D – BED-MATERIAL SIEVE CURVE

FIG. 4–4 SIEVE ANALYSES FOR FLOW CONDITION NO. 1



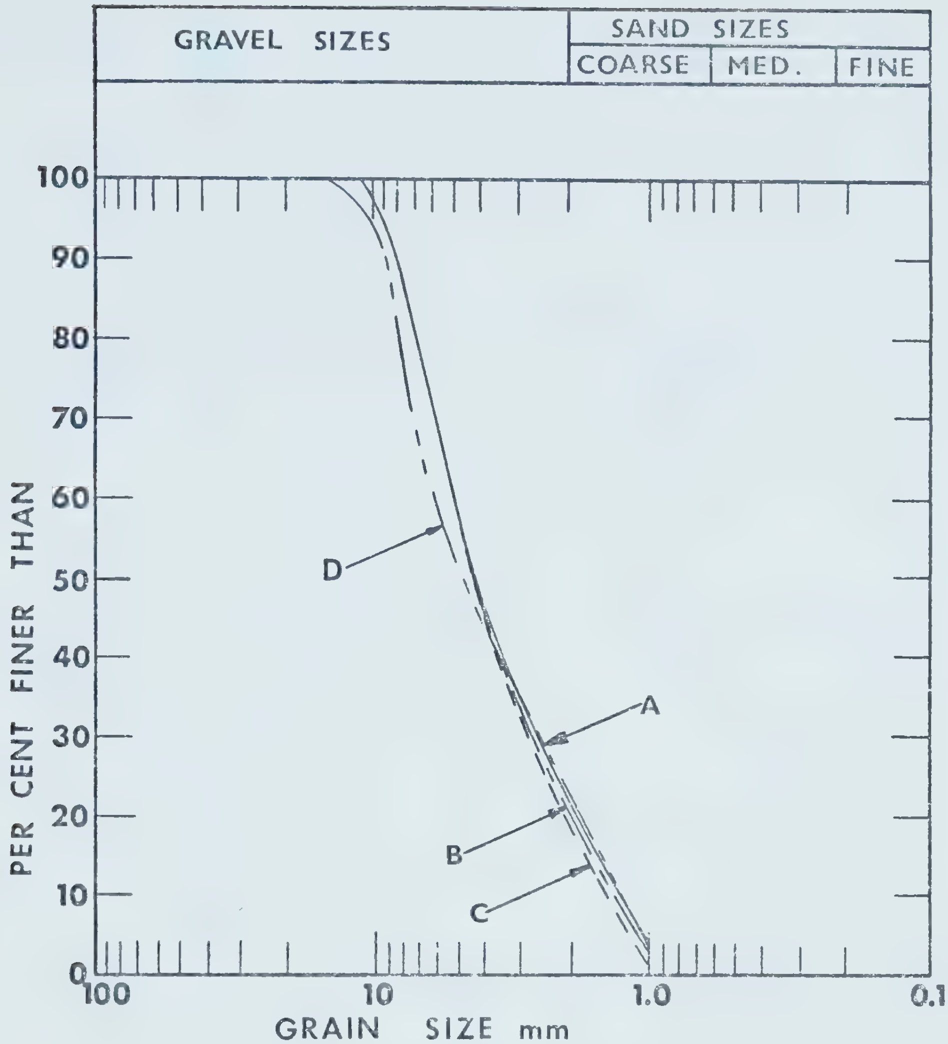
A- SLICE SAMPLER SIEVE CURVE

B- 2.4 mm MESH BASKET SIEVE CURVE

C - 1.4 mm MESH BASKET SIEVE CURVE

D -BED-MATERIAL SIEVE CURVE

FIG. 4-5 SIEVE ANALYSES FOR FLOW CONDITION NO. 2



A –SLICE SAMPLER SIEVE CURVE

B – 2.4 mm MESH BASKET SIEVE CURVE

C – 1.4 mm MESH BASKET SIEVE CURVE

D–BED-MATERIAL SIEVE CURVE

FIG. 4-6 SIEVE ANALYSES FOR FLOW CONDITION NO. 3

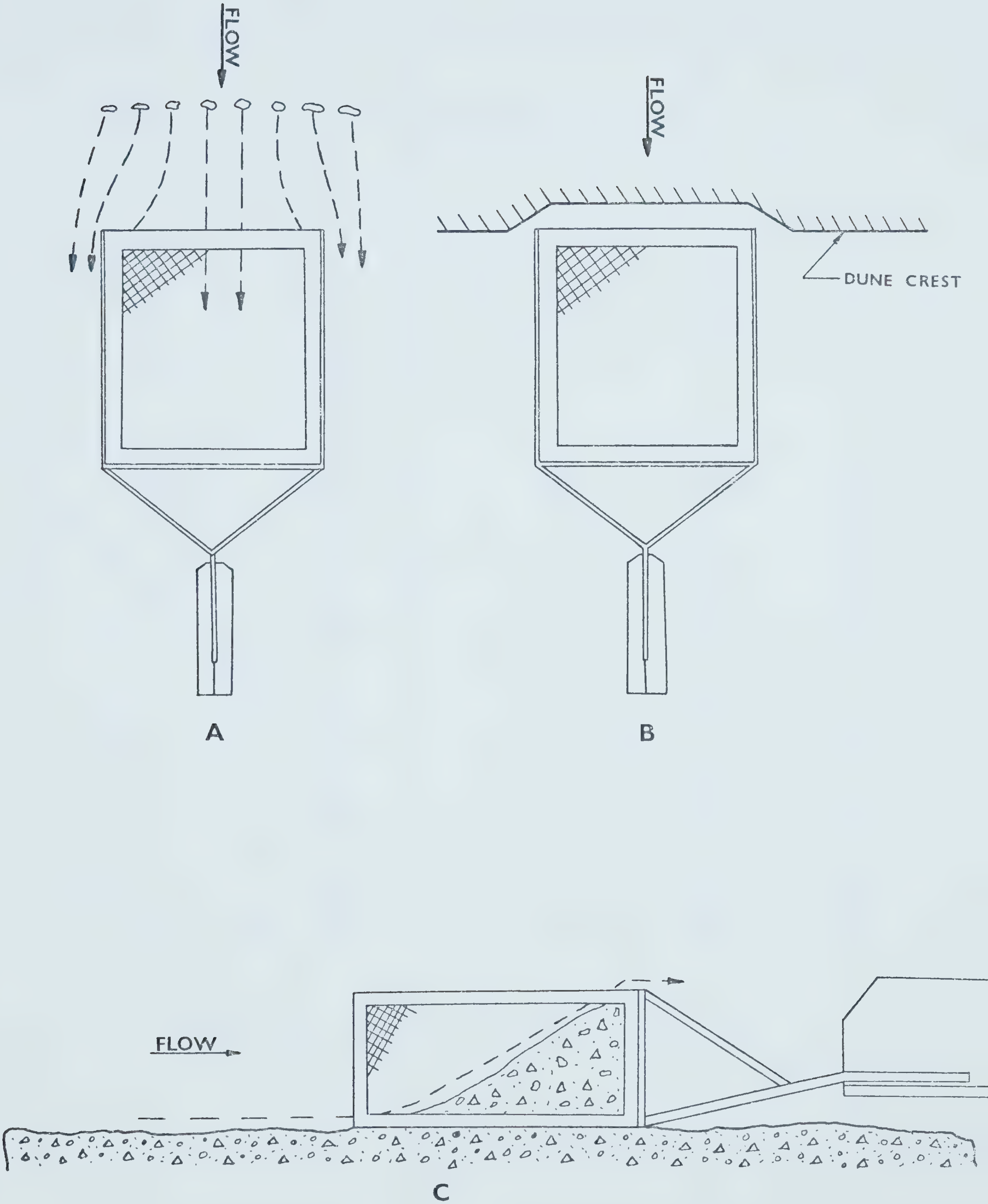
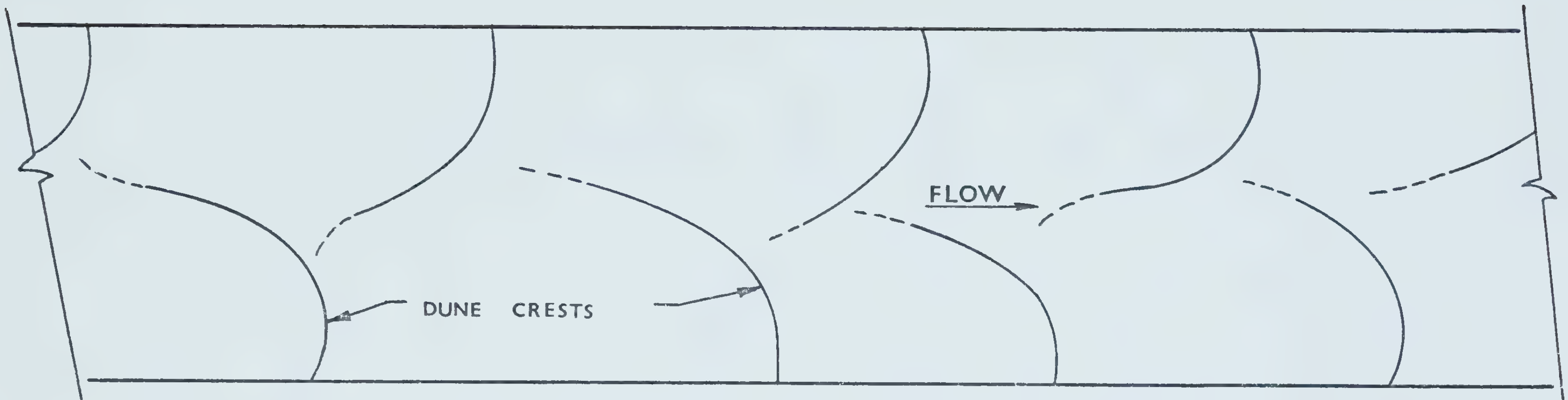
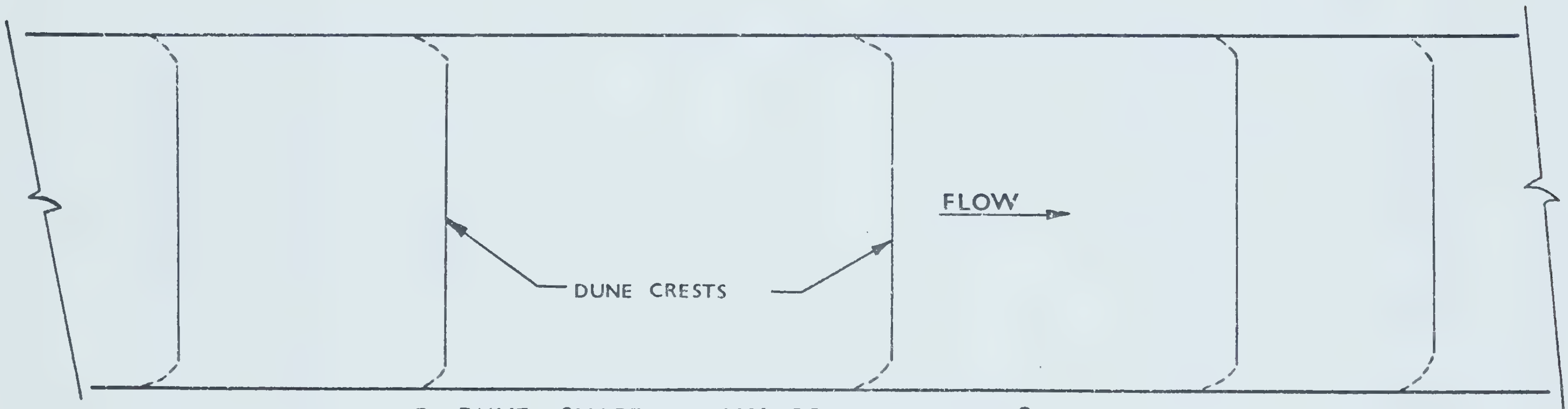


FIG.4-7 POSSIBLE CAUSES OF LOW SAMPLING EFFICIENCY

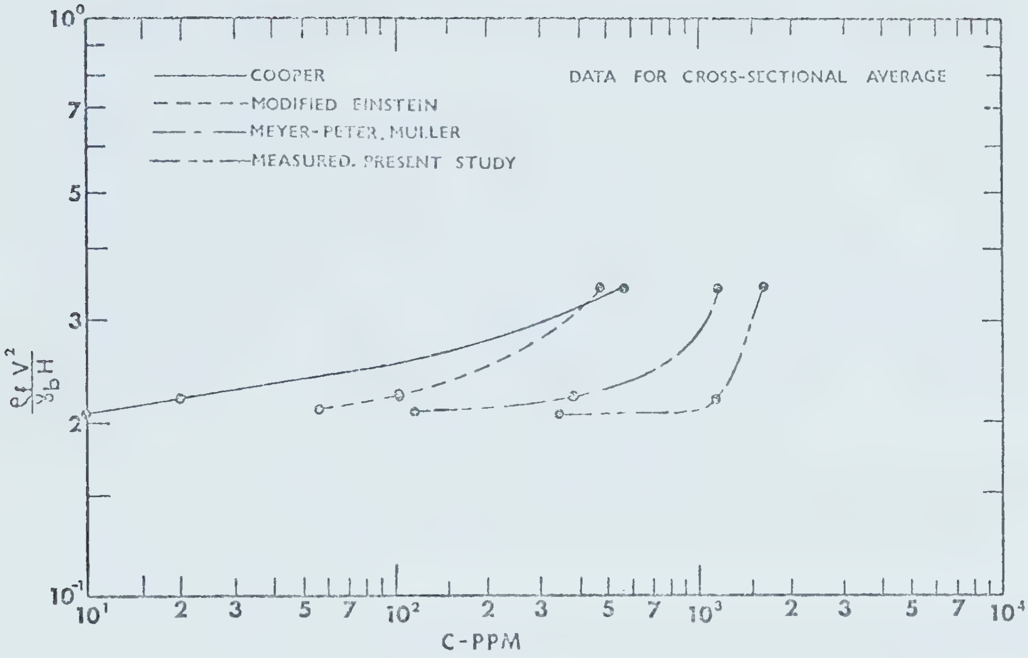


A - DUNE SHAPE - FLOW CONDITION NOS. 1 AND 3

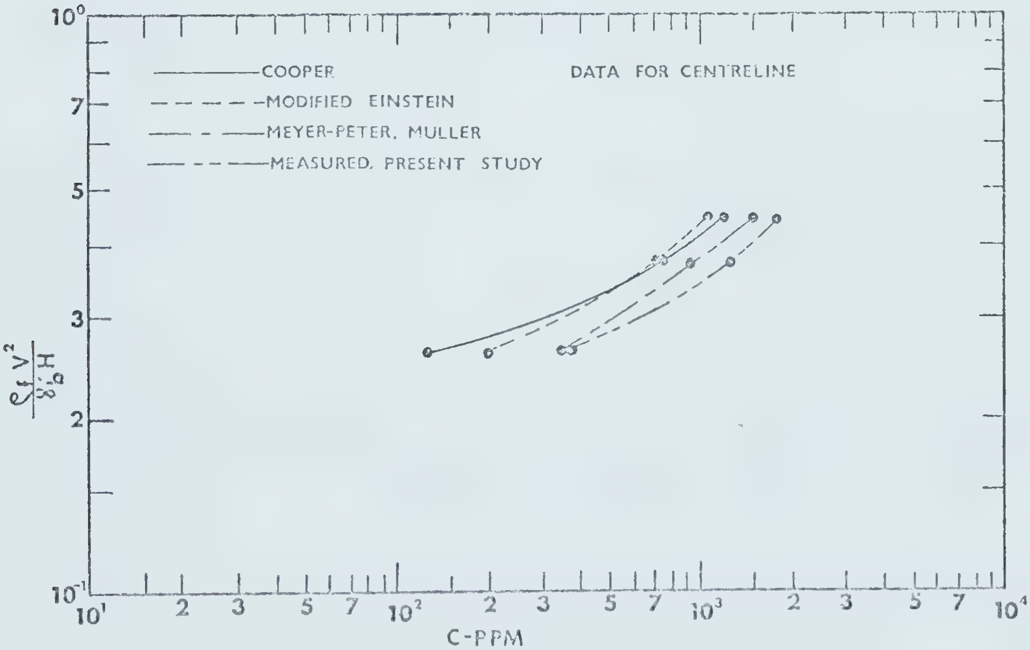


B - DUNE SHAPE - FLOW CONDITION NO. 2

FIG. 4-8 PLAN VIEW OF BED-FORM SHAPES

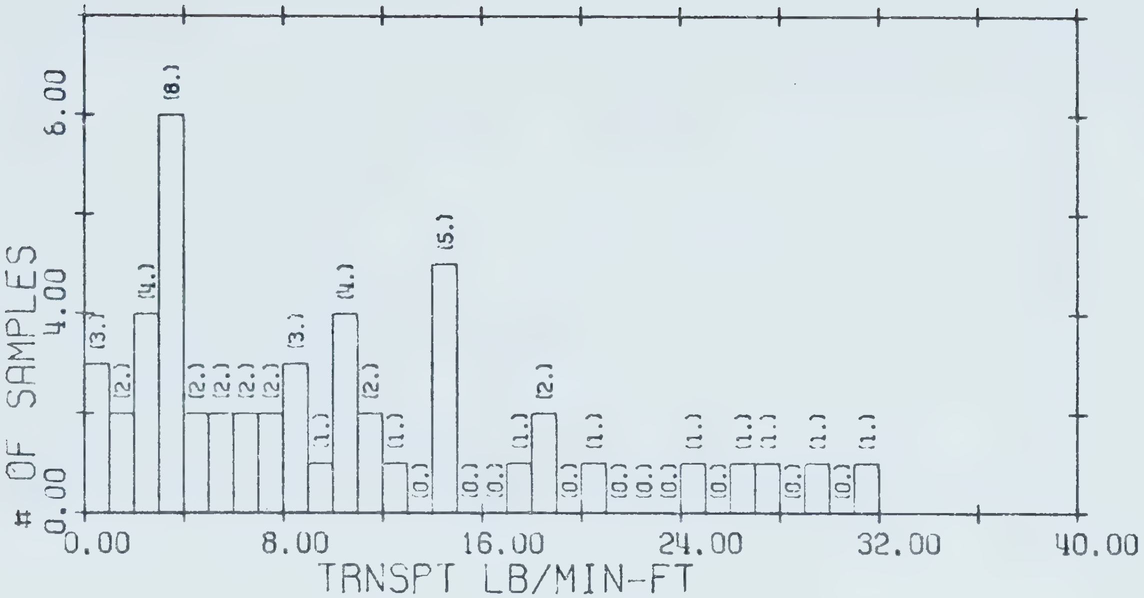


A

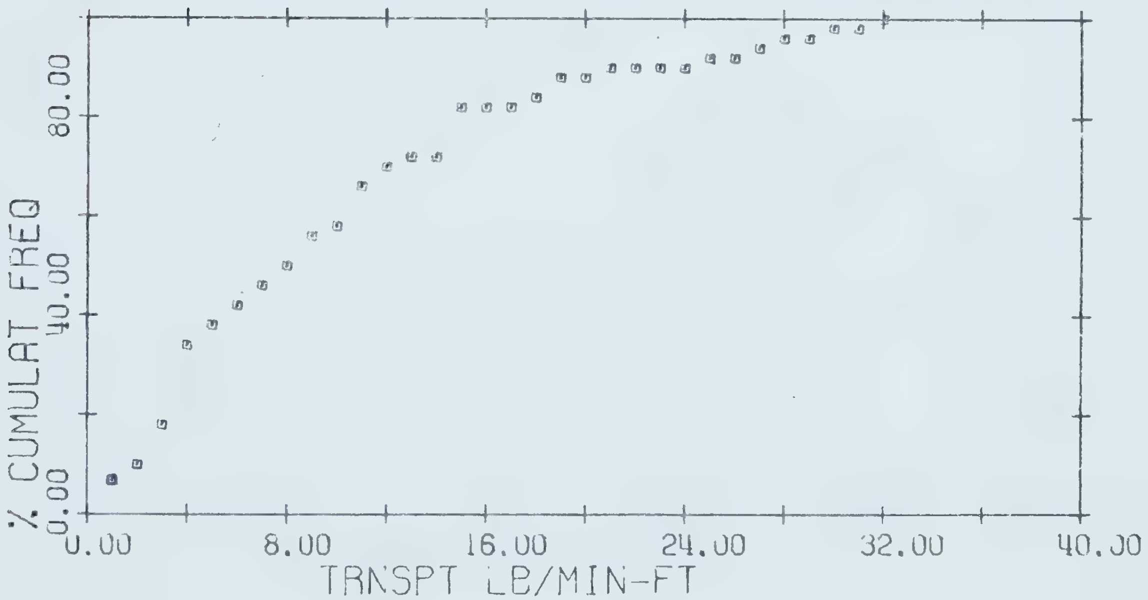


B

FIG. 5-1 COMPARISON OF TRANSPORT PREDICTION TECHNIQUES



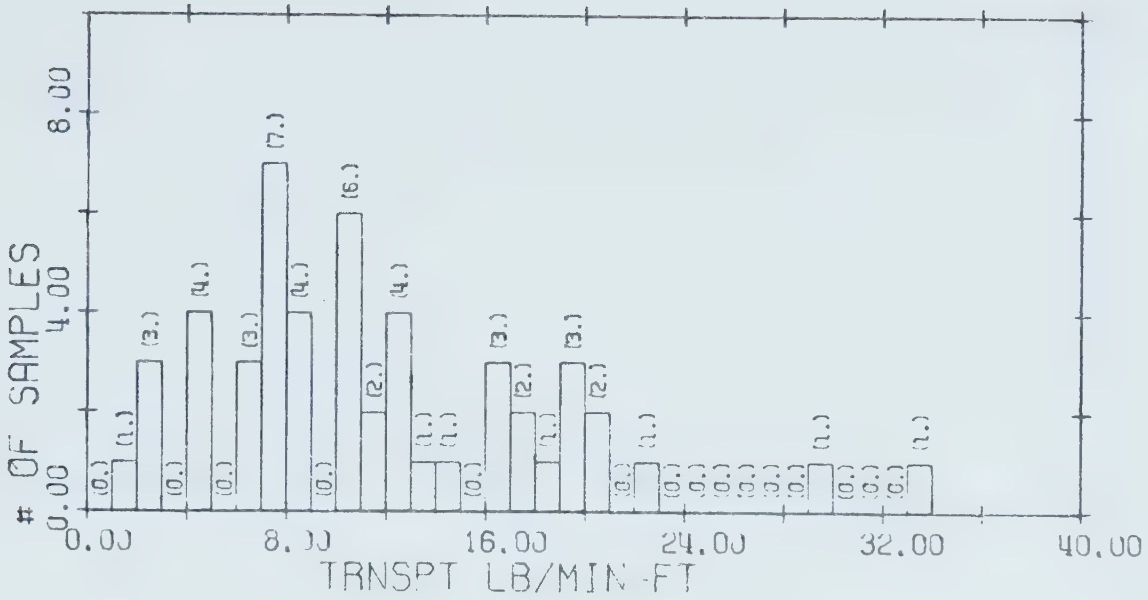
BEDLOAD TRANSPORT HISTOGRAM



CUMULATIVE FREQUENCY DIAGRAM

SLICE SAMPLER DATA
SAMPLE DURATION=10 SEC

FIG. 5-2-A FLOW CONDITION NO. 3 - TRANSPORT RATE DISTRIBUTIONS



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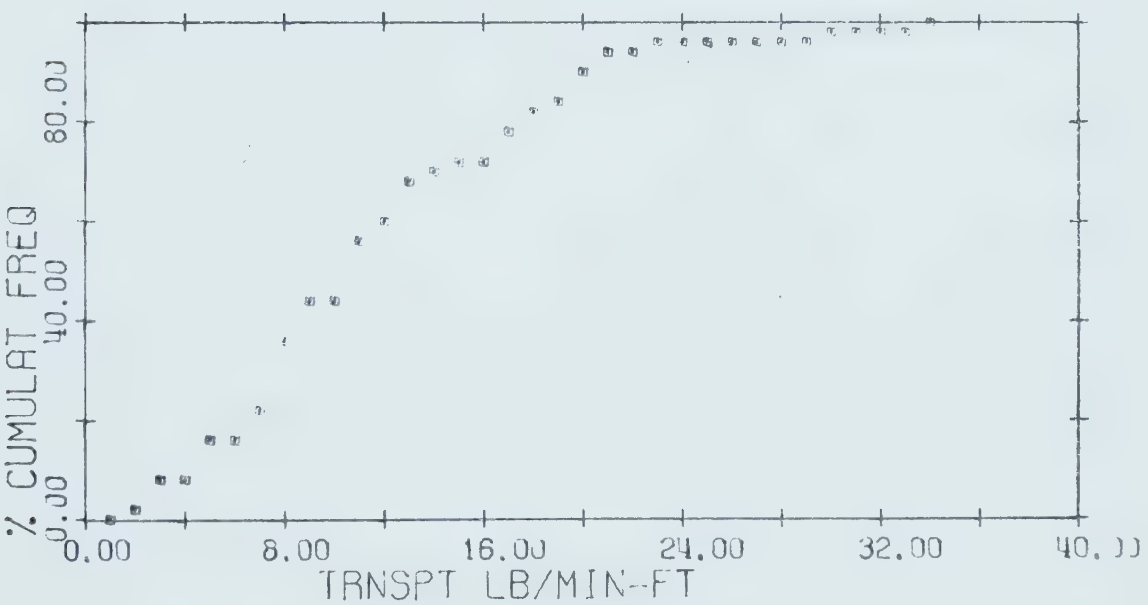
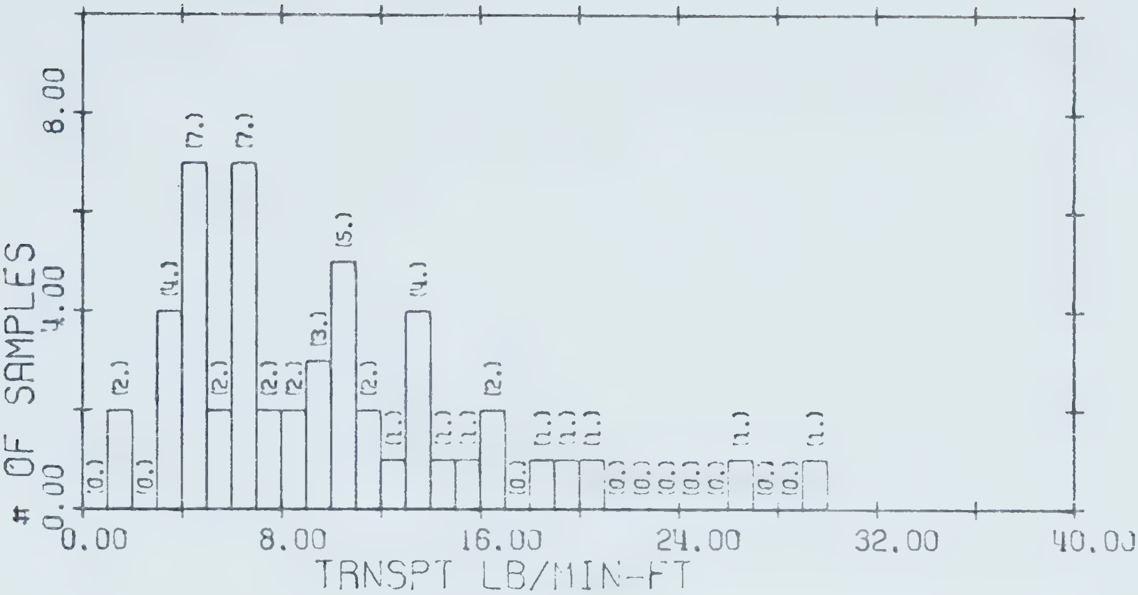


CUMULATIVE FREQUENCY DIAGRAM

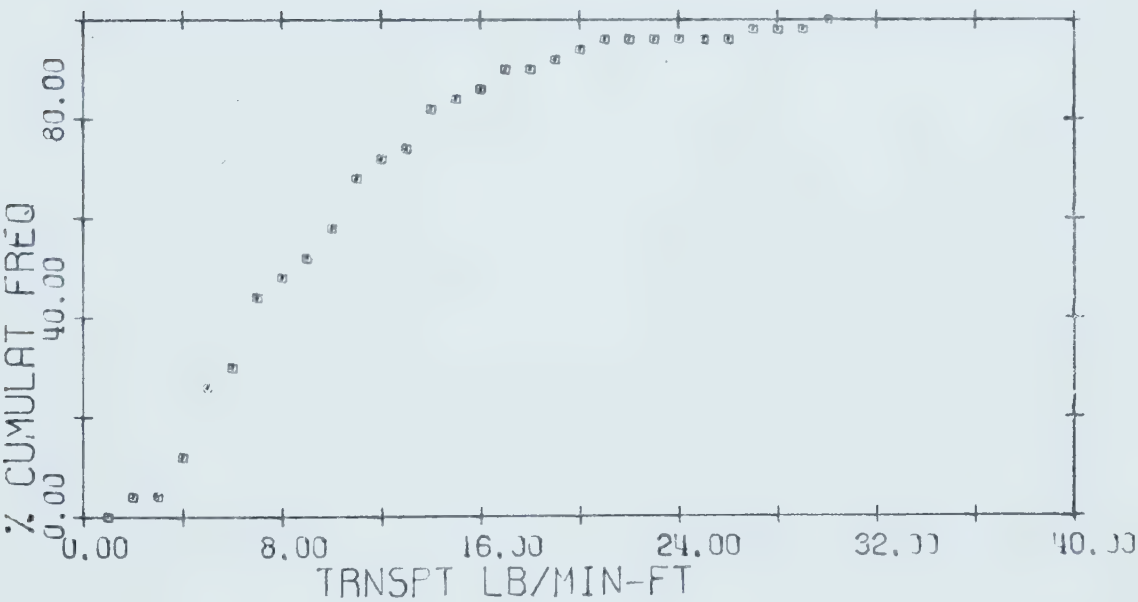
SLICE SAMPLER DATA

SAMPLE DURATION = 20 SEC

FIG. 5-2-B FLOW CONDITION NO. 3 - TRANSPORT RATE DISTRIBUTIONS



BEDLØAD TRANSPØRT HISTOGRAM

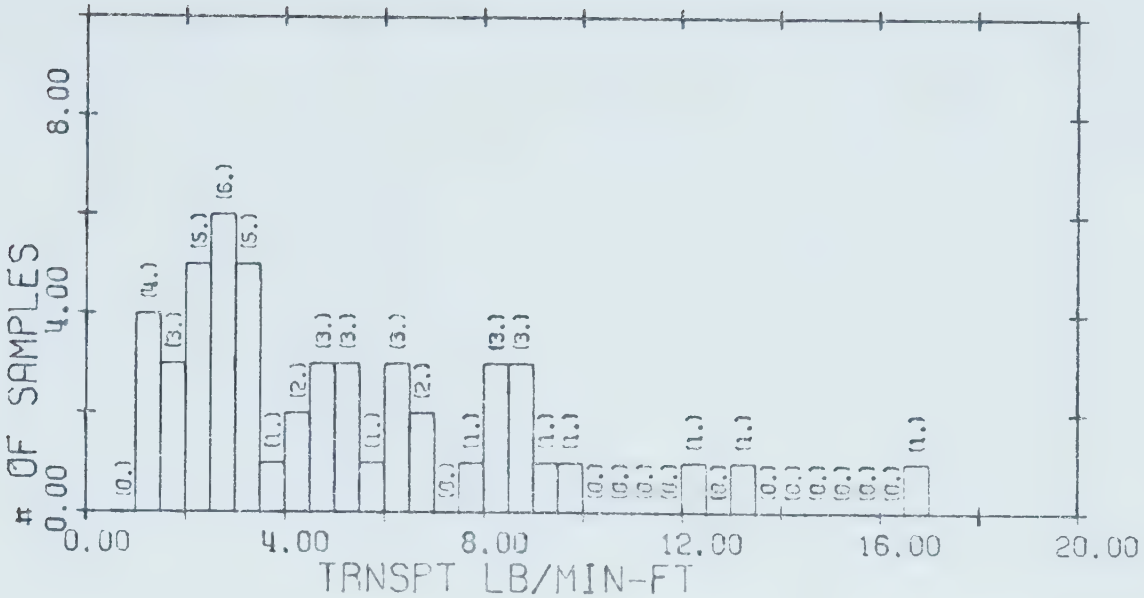


CUMULATIVE FREQUENCY DIAGRAM

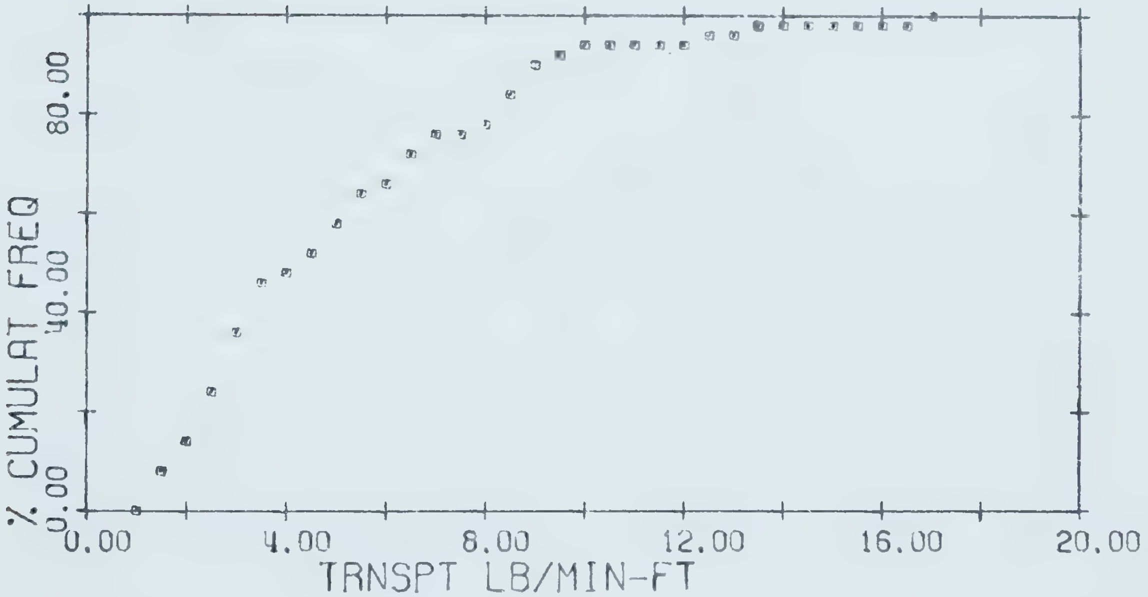
SLICE SAMPLER DATA

SAMPLE DURATION=30 SEC

FIG. 5-2-C FLOW CONDITION NO.3 - TRANSPORT RATE DISTRIBUTION



BEDLOAD TRANSPORT HISTOGRAM

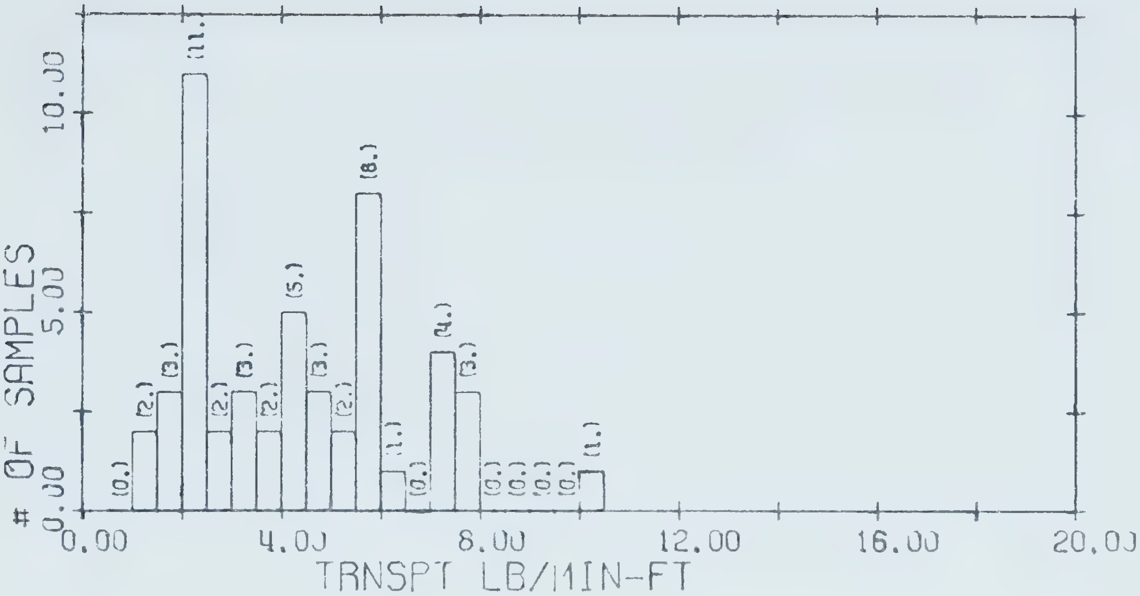


CUMULATIVE FREQUENCY DIAGRAM

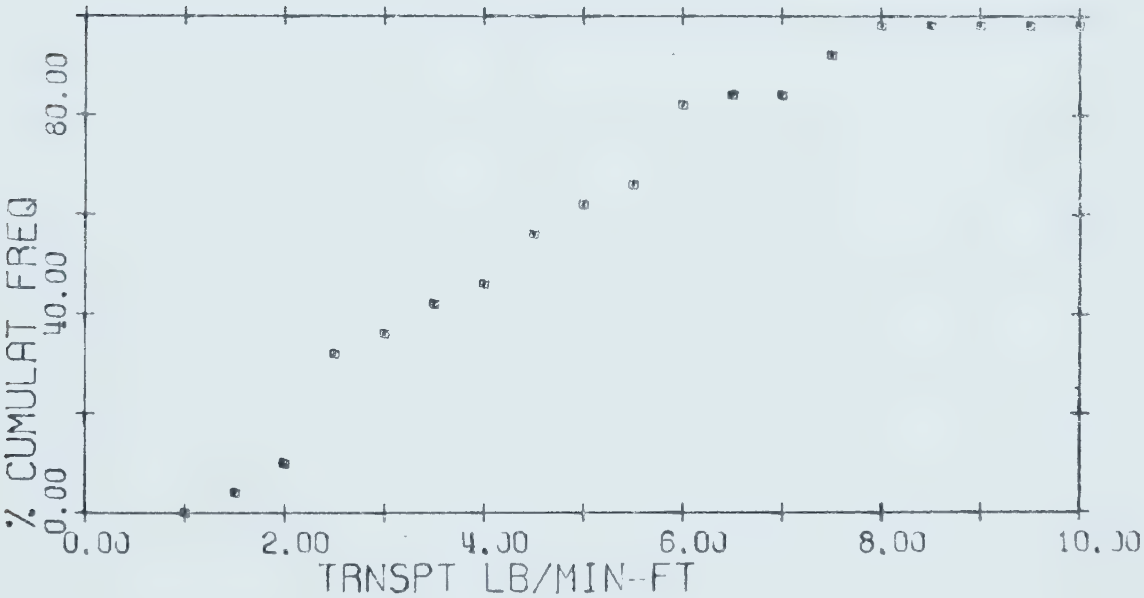
1.4 mm BASKET SAMPLER DATA

SAMPLE DURATION = 10 SEC

FIG. 5-2-D FLOW CONDITION NO. 3 - TRANSPORT RATE DISTRIBUTIONS



BEDLOAD TRANSPORT HISTOGRAM

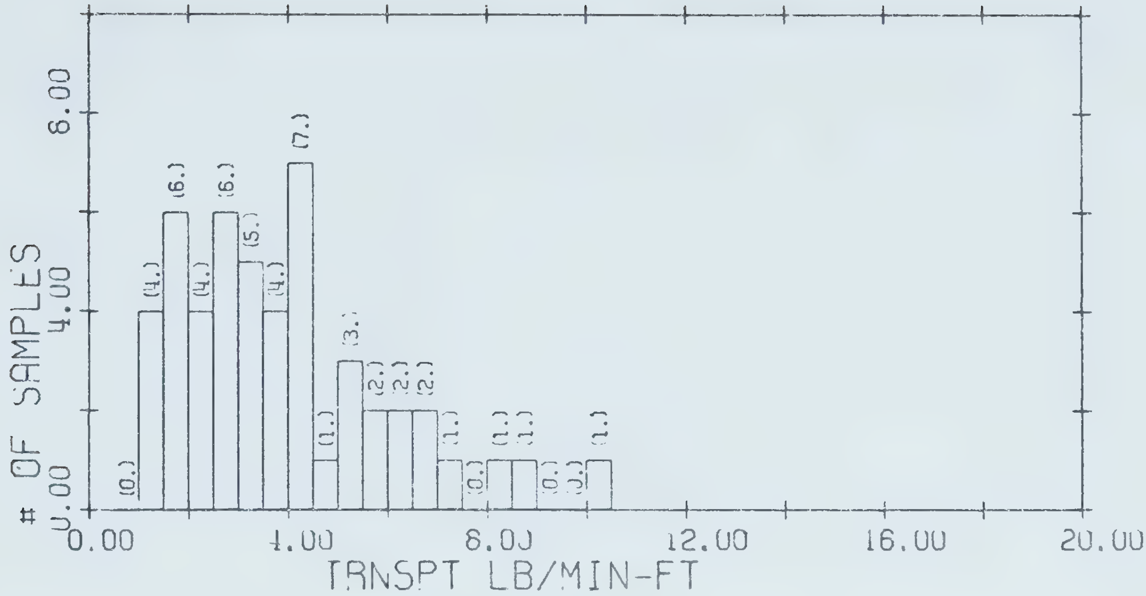


CUMULATIVE FREQUENCY DIAGRAM

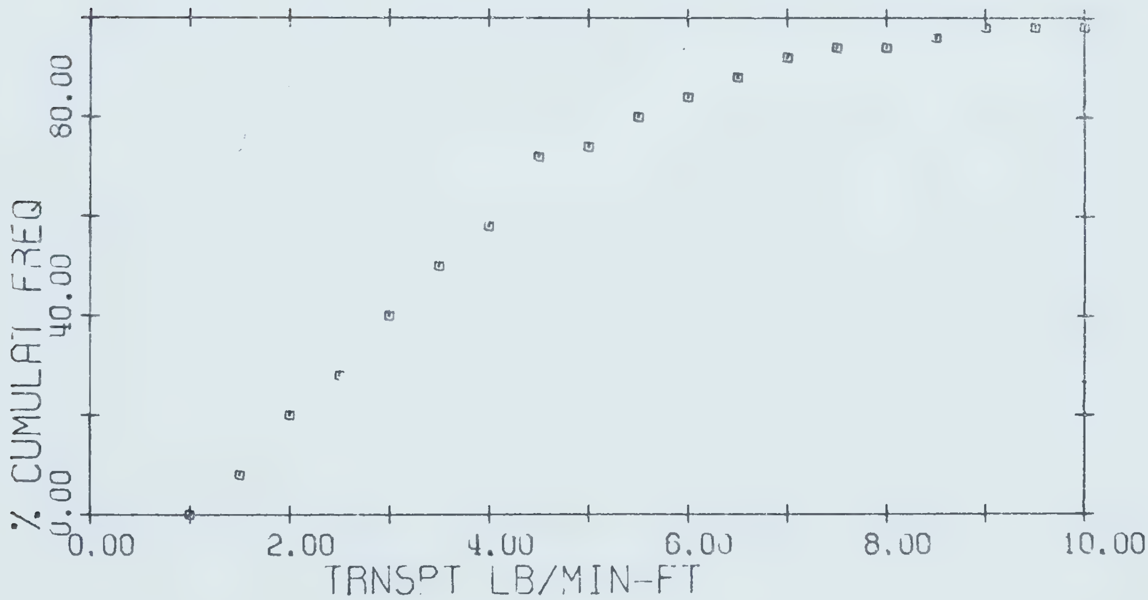
1.4mm BASKET SAMPLER DATA

SAMPLE DURATION=20 SEC

FIG. 5-2-E FLOW CONDITION NO. 3 – TRANSPORT RATE DISTRIBUTIONS



BEDLOAD TRANSPORT HISTOGRAM

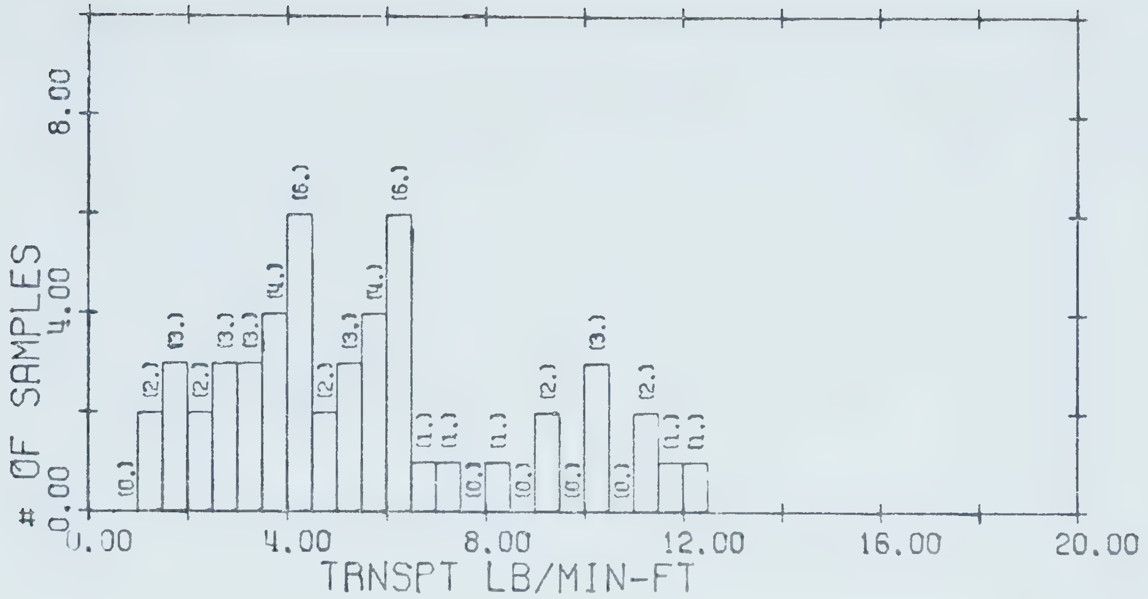


CUMULATIVE FREQUENCY DIAGRAM

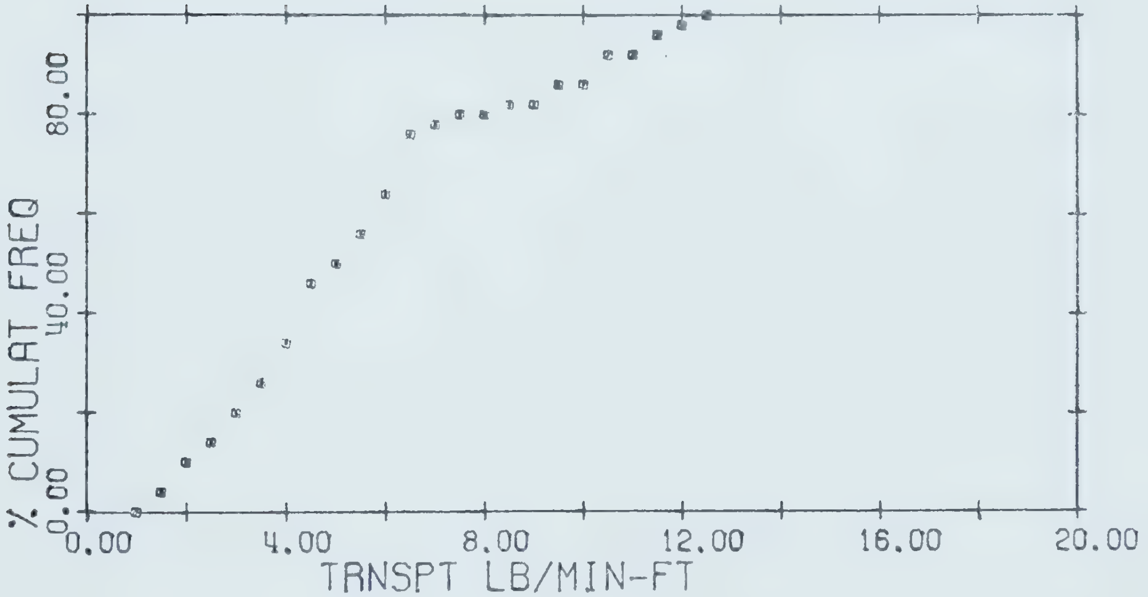
1.4mm BASKET SAMPLER DATA

SAMPLE DURATION = 30 SEC

FIG. 5-2-F FLOW CONDITION NO. 3 – TRANSPORT RATE DISTRIBUTIONS



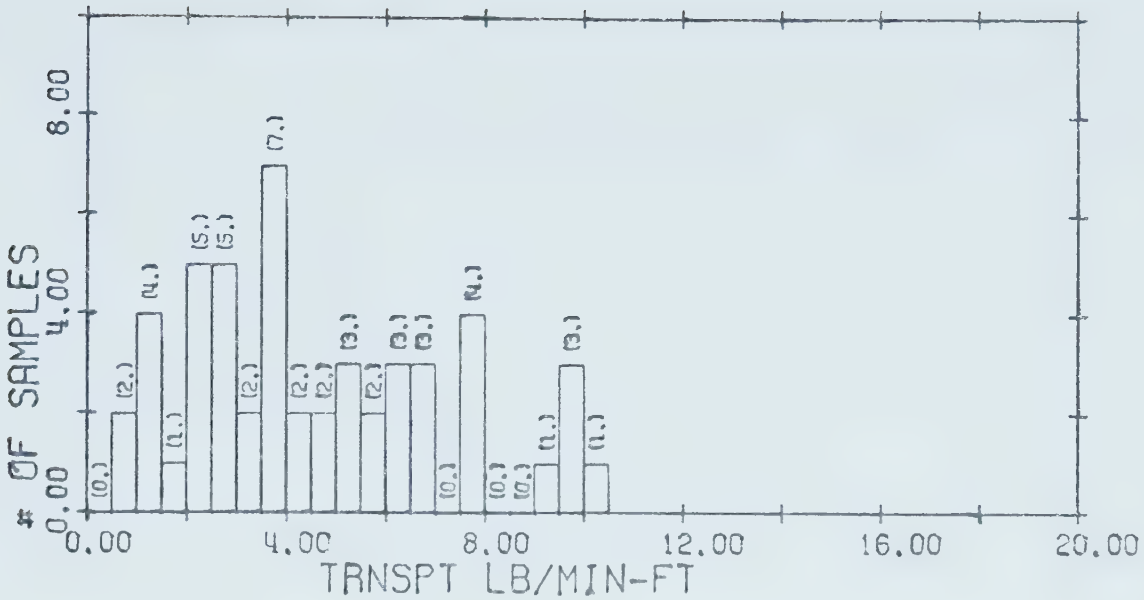
BEDLØAD TRANSPØRT HISTØGRAM



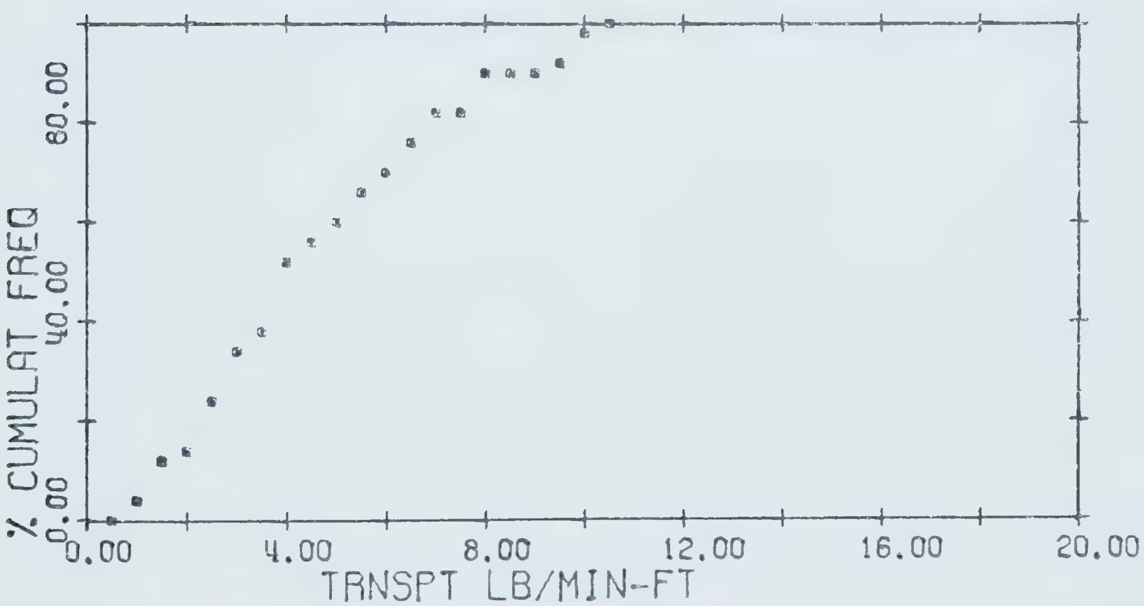
CUMULATIVE FREQUENCY DIAGRAM

2.4 mm BASKET SAMPLER DATA
SAMPLE DURATION = 10 SEC

FIG. 5-2-G FLOW CONDITION NO. 3 - TRANSPORT RATE DISTRIBUTIONS



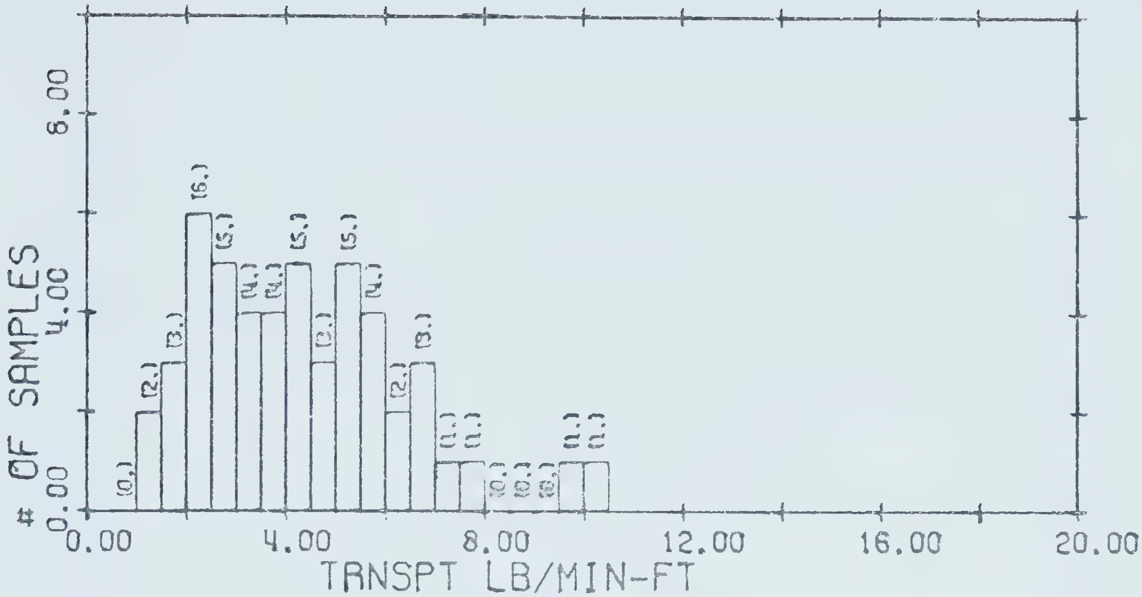
BEDLOAD TRANSPORT HISTOGRAM



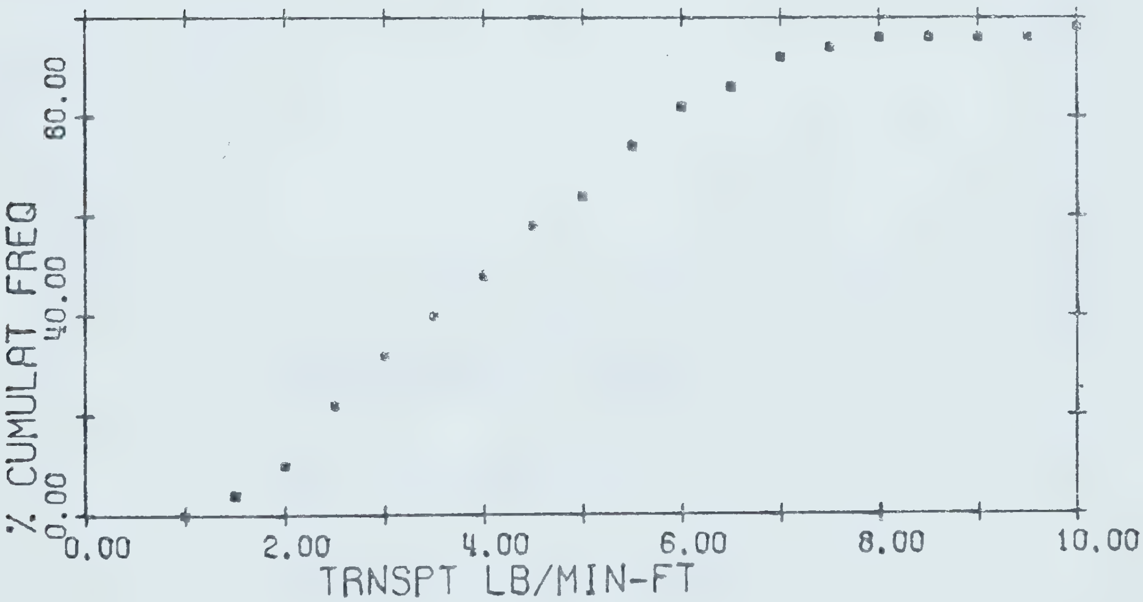
CUMULATIVE FREQUENCY DIAGRAM

2.4mm BASKET SAMPLER DATA
SAMPLE DURATION= 20 SEC

FIG. 5-2-H FLOW CONDITION NO. 3 - TRANSPORT RATE DISTRIBUTIONS



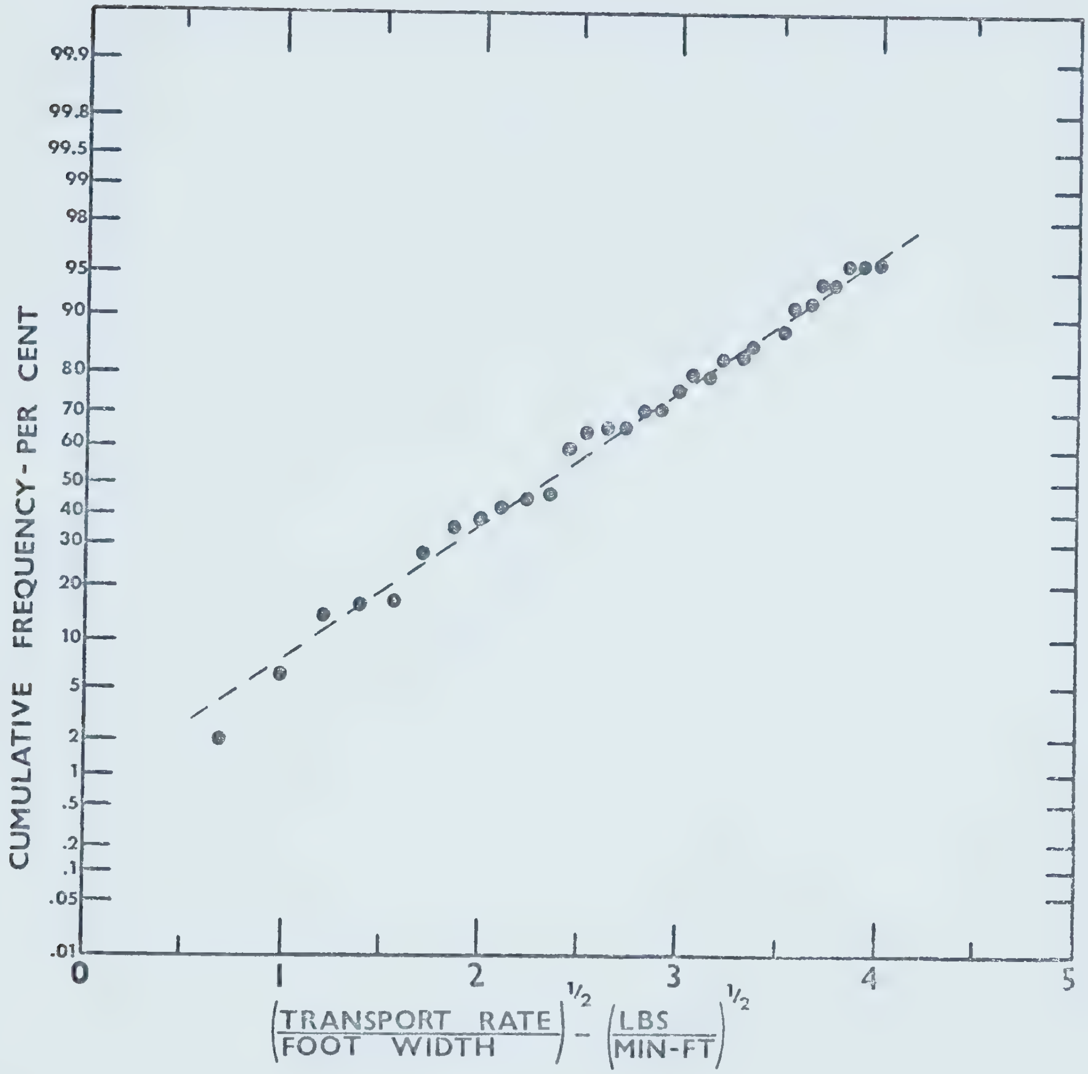
BEDLOAD TRANSPORT HISTOGRAM



CUMULATIVE FREQUENCY DIAGRAM

2.4 mm BASKET SAMPLER DATA
SAMPLE DURATION=30 SEC

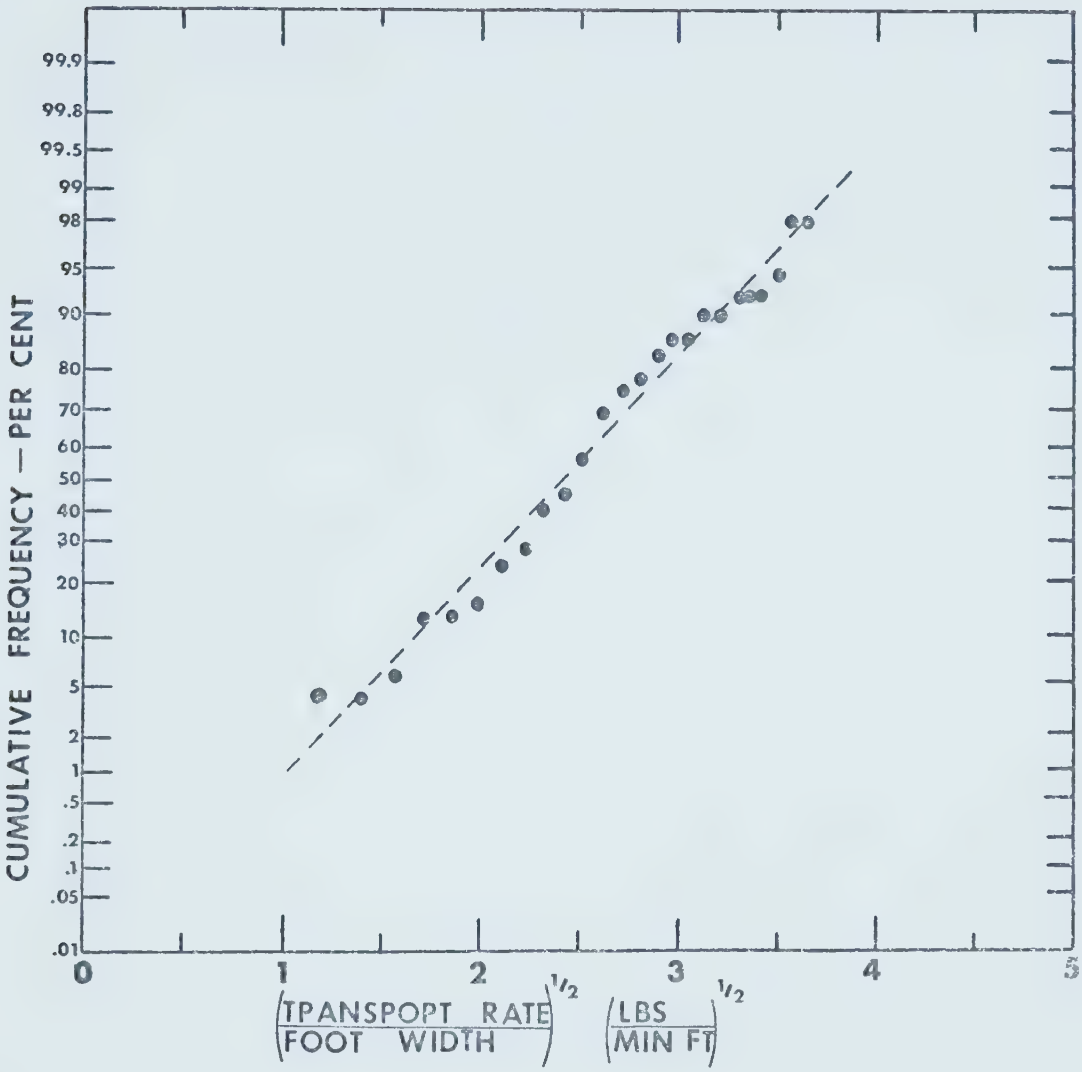
FIG. 5-2-1 FLOW CONDITION NO.3-TRANSPORT RATE DISTRIBUTIONS



FLOW CONDITION NO. 1

SAMPLING DURATION – 30 SEC

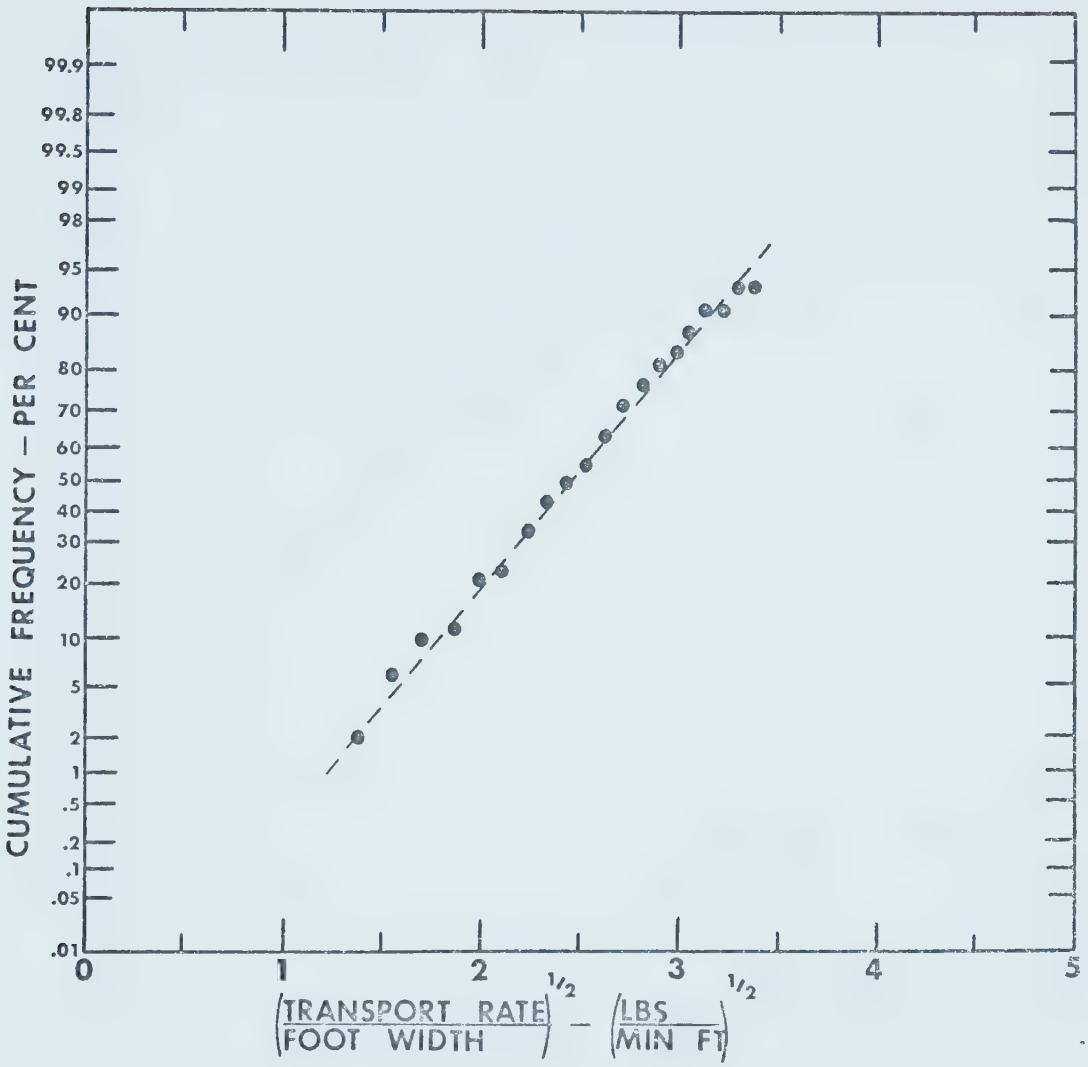
FIG.5-3-A NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 1

SAMPLING DURATION – 45 SEC

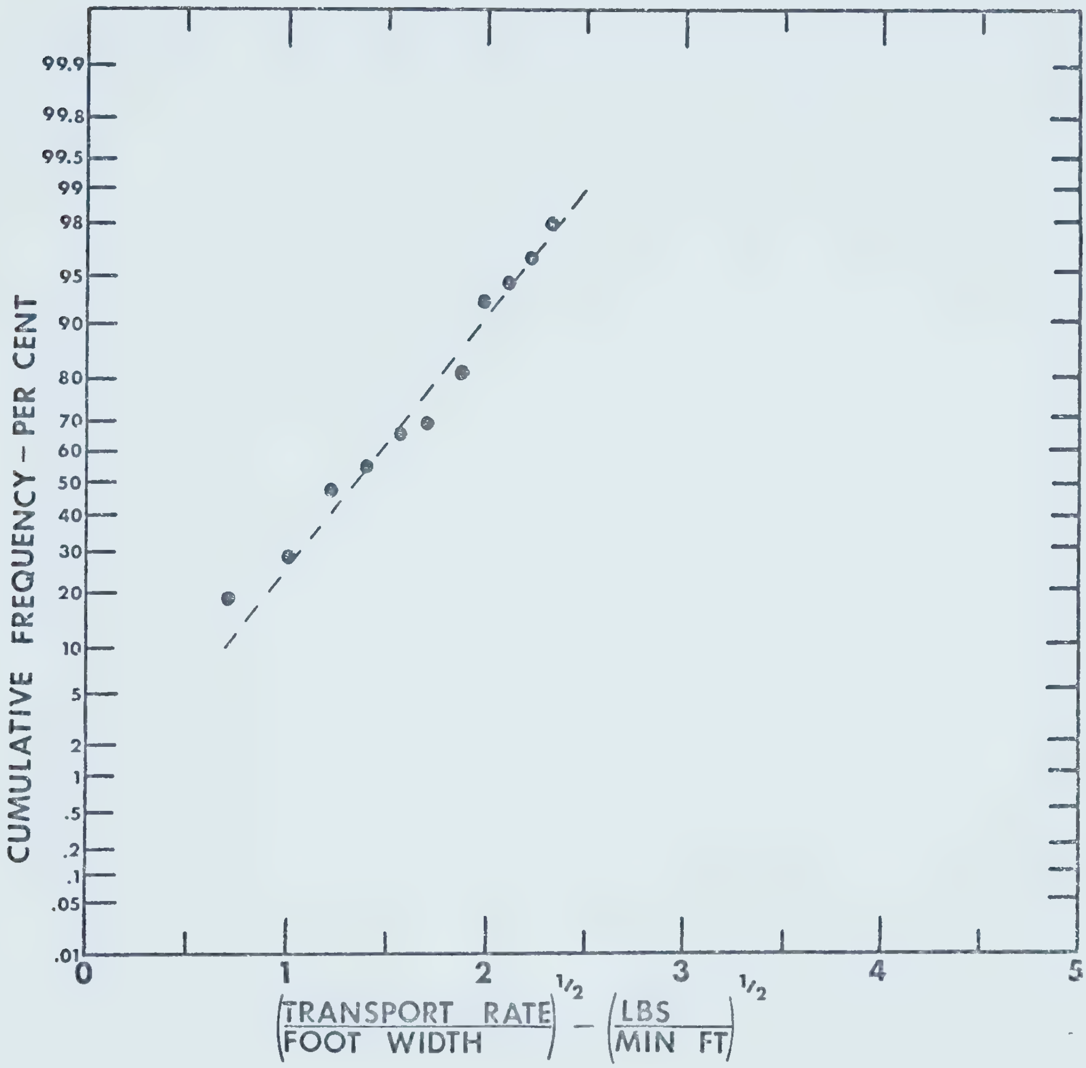
FIG. 5-3-B NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 1

SAMPLING DURATION—60 SEC

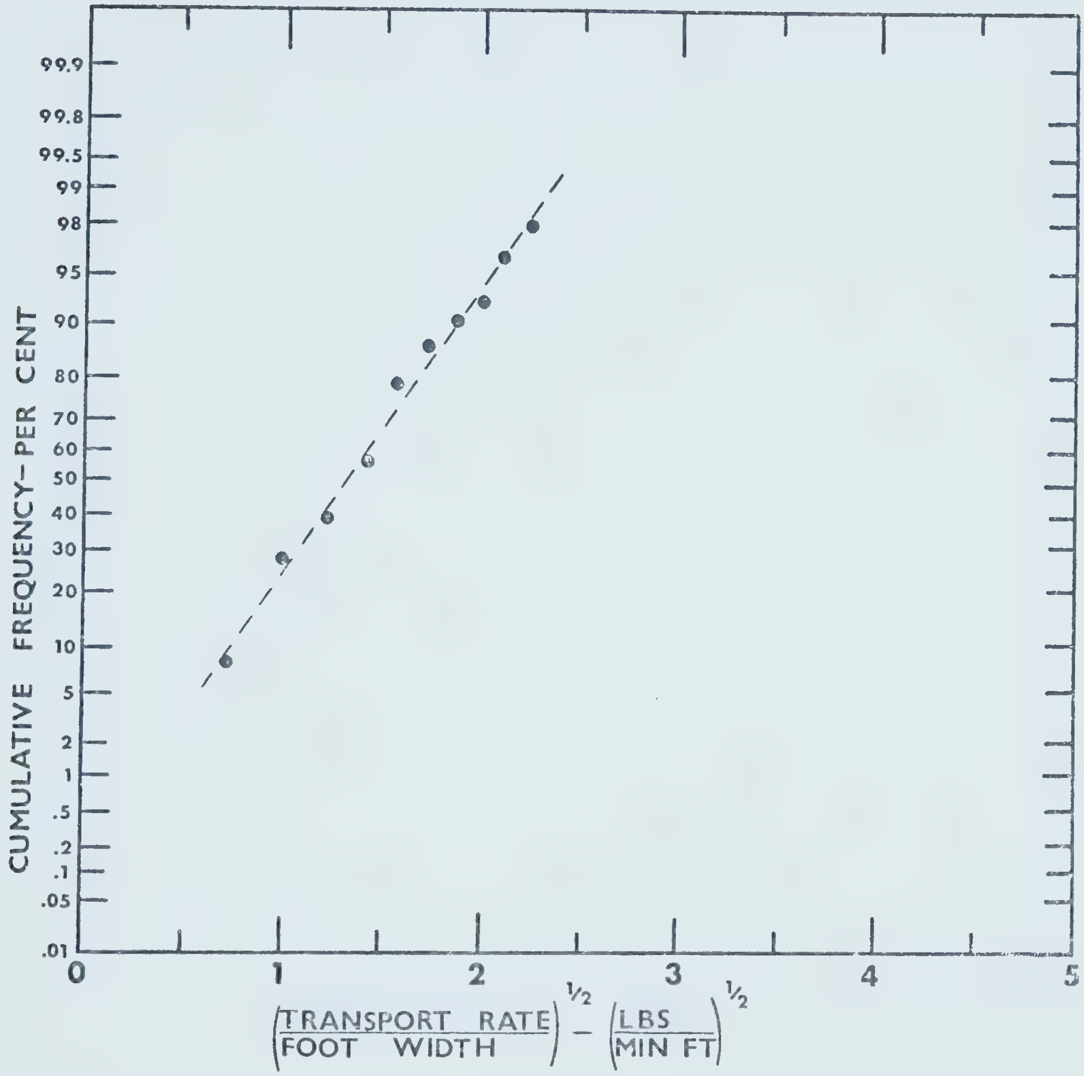
FIG. 5-3-C NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 2

SAMPLING DURATION – 60 SEC

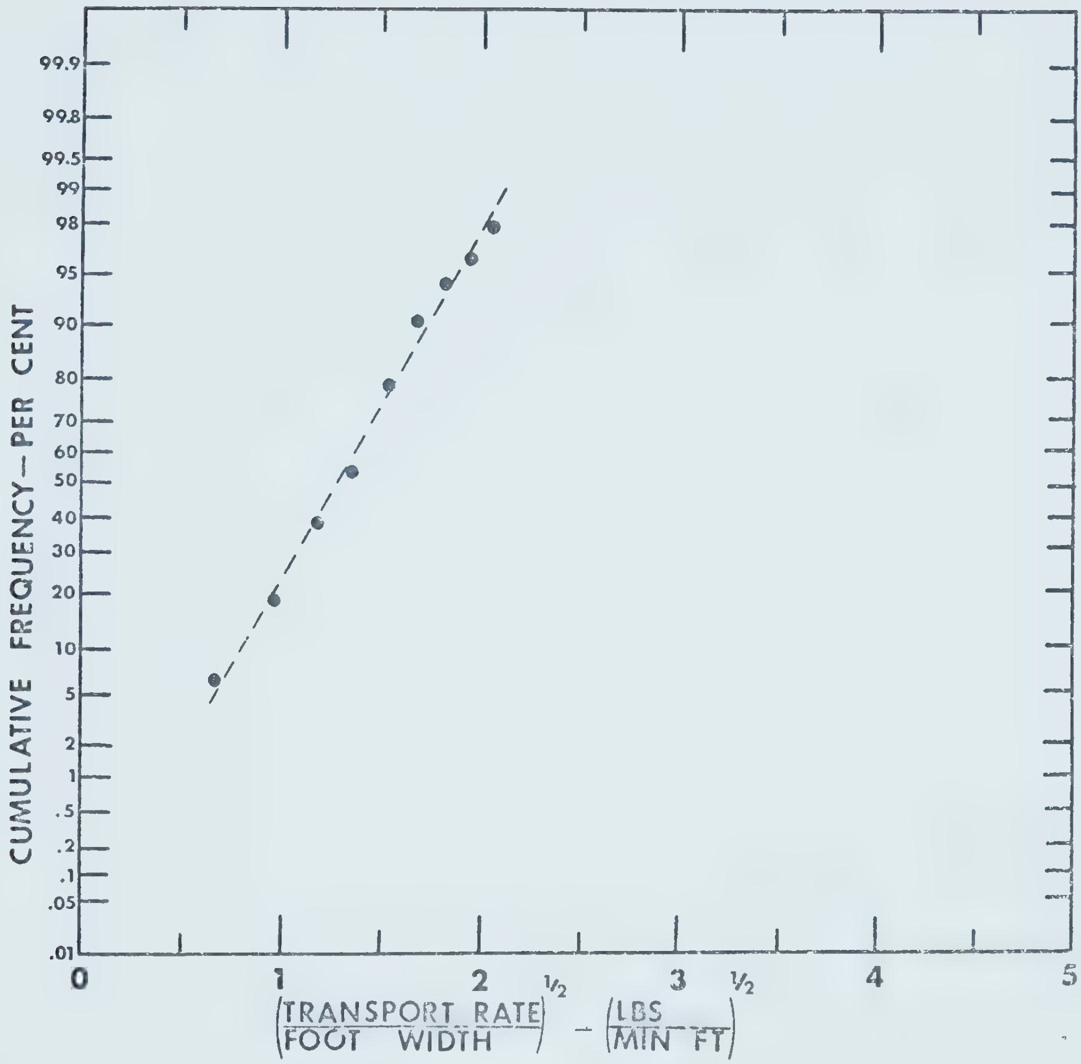
FIG. 5-3-D NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 2

SAMPLING DURATION - 120 SEC

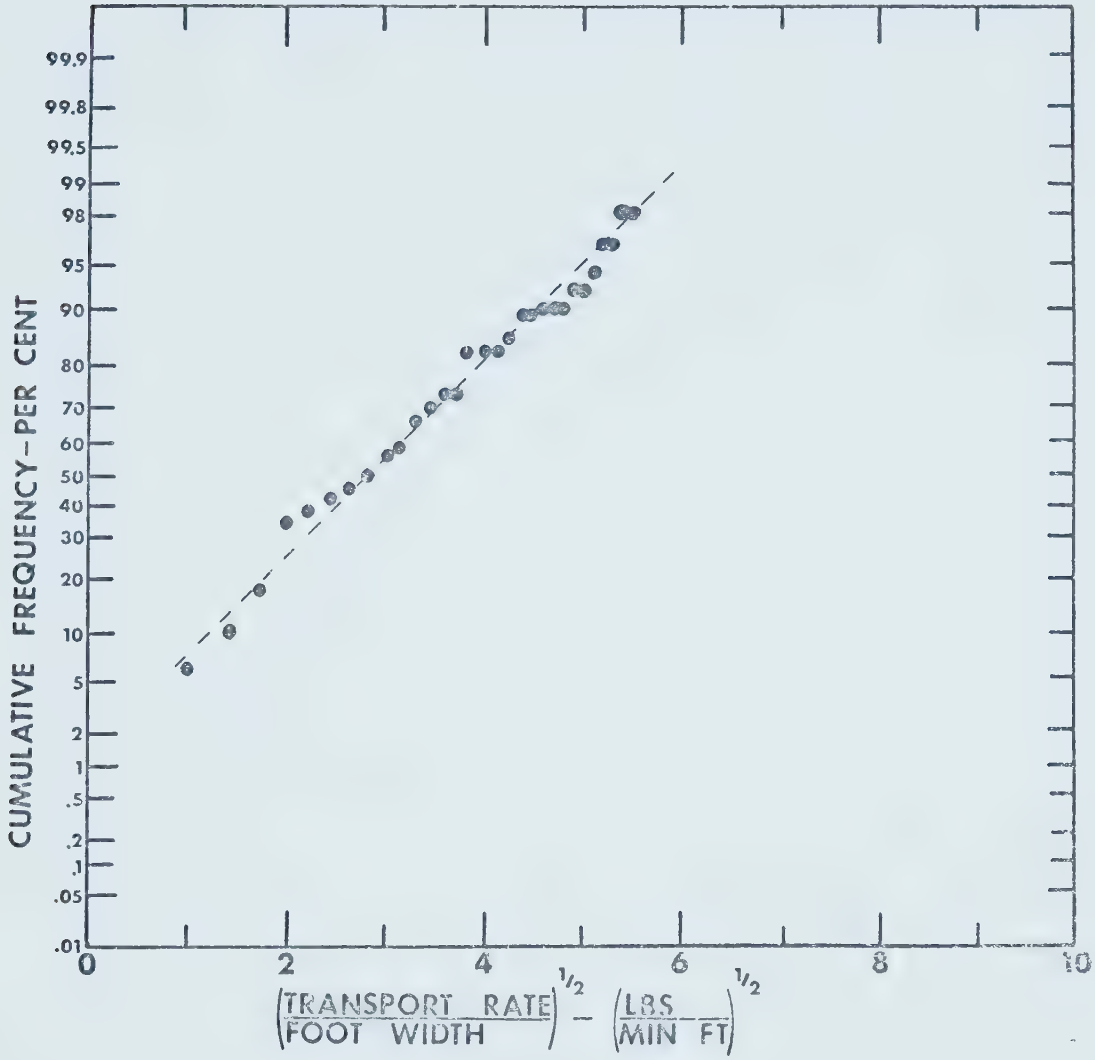
FIG. 5-3-E NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 2

SAMPLING DURATION – 180 SEC

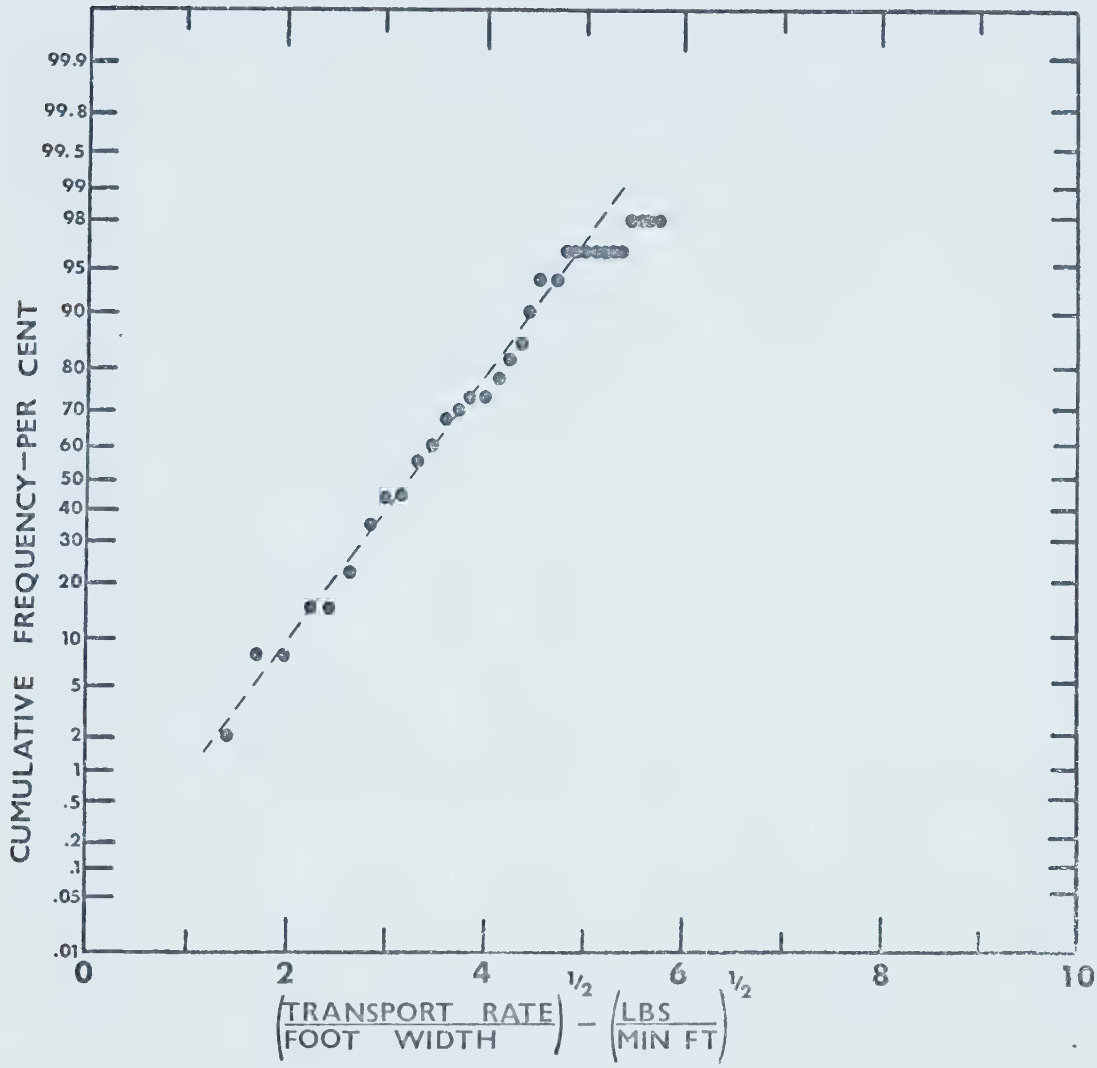
FIG. 5-3-F NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 3

SAMPLING DURATION-10 SEC

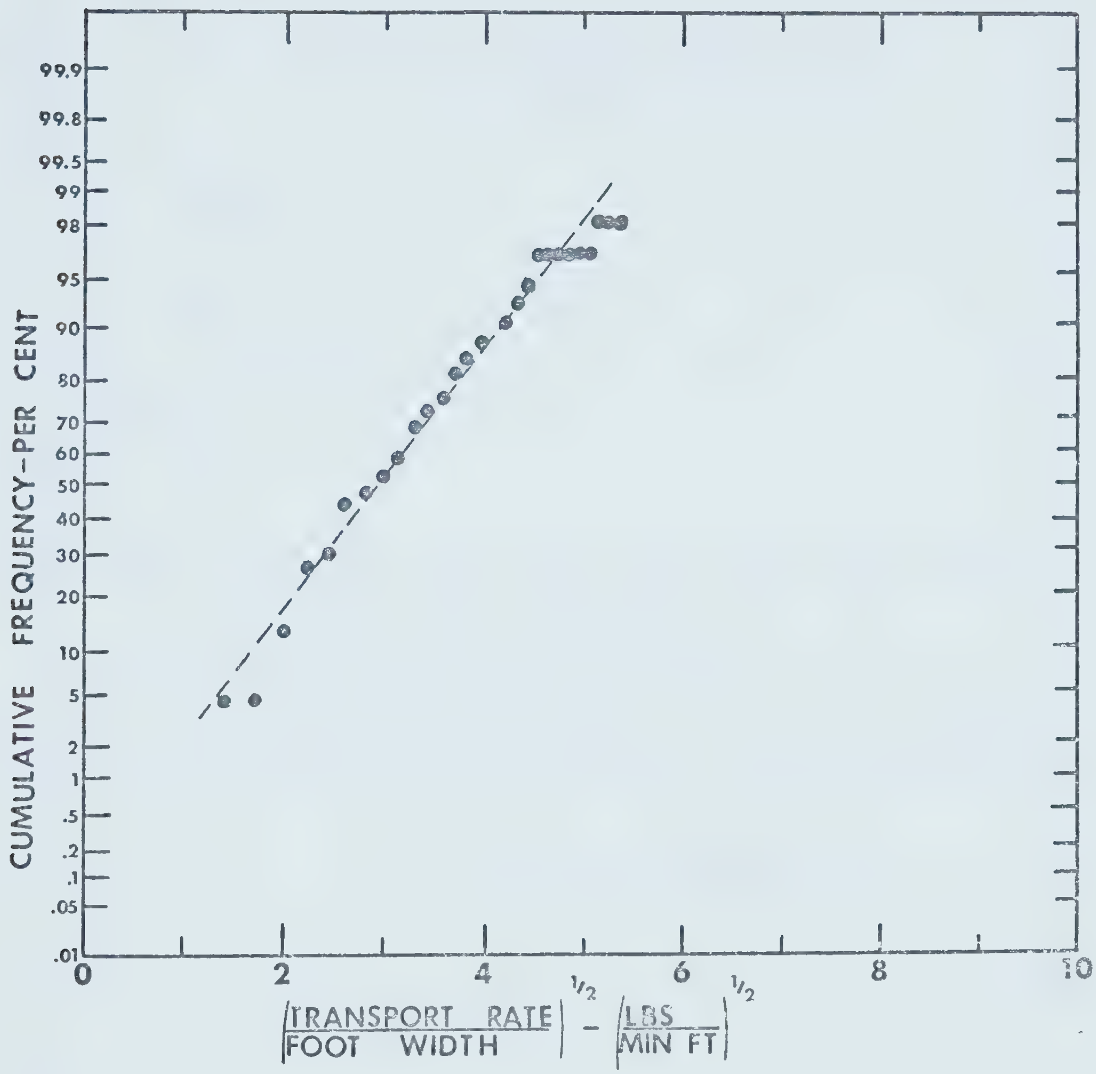
FIG. 5-3-G NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 3

SAMPLING DURATION – 20 SEC

FIG. 5-3-H NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE



FLOW CONDITION NO. 3

SAMPLING DURATION - 30 SEC

FIG. 5-3-1 NORMAL PROBABILITY PLOT OF THE SQUARE ROOT OF THE UNIT WIDTH TRANSPORT RATE

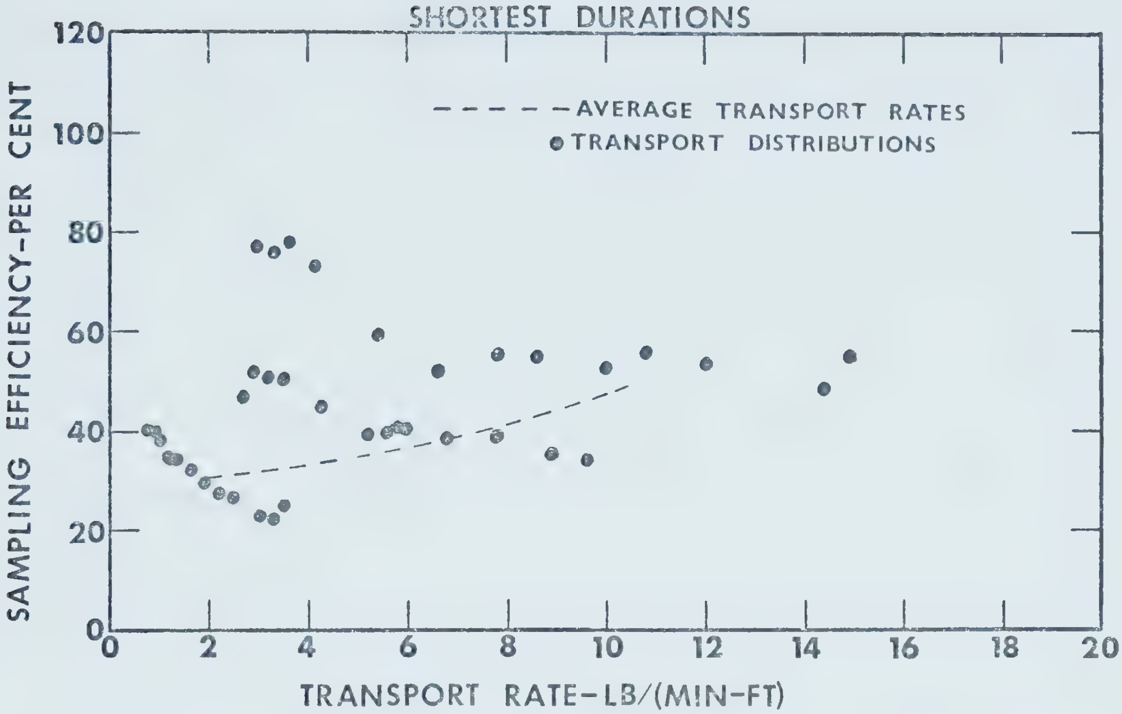


FIG. 5-4-A TRANSPORT-EFFICIENCY RELATION (FROM DIST'NS) (1.4mm BASKET)

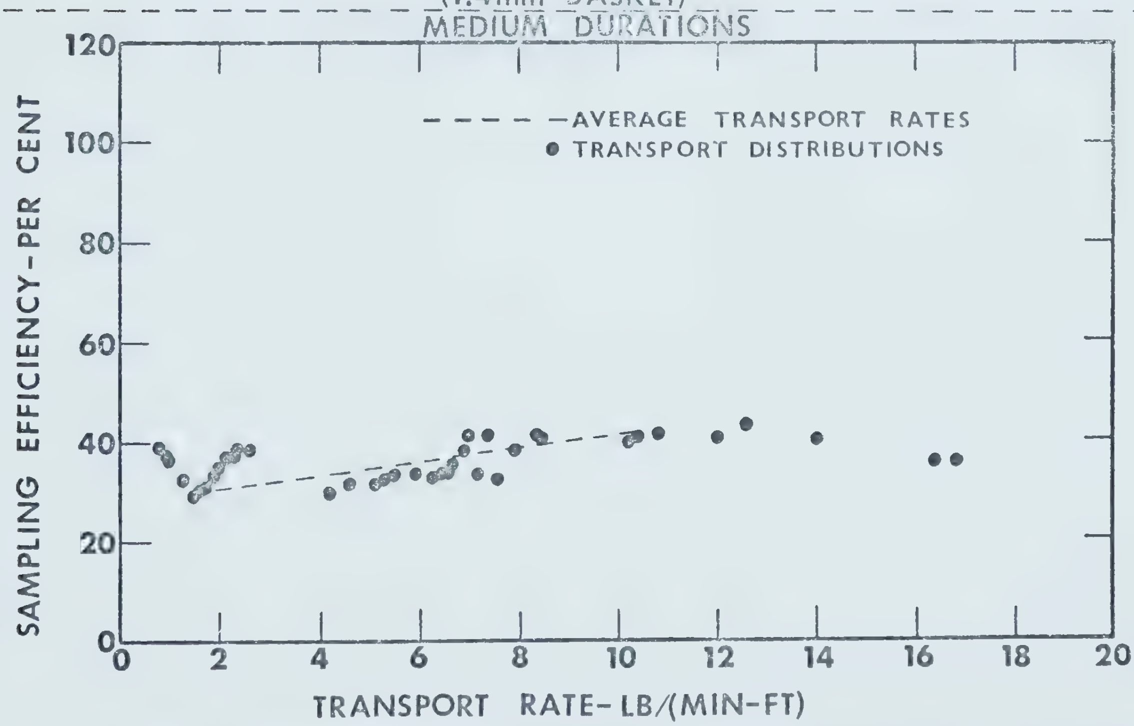


FIG. 5-4-B TRANSPORT-EFFICIENCY RELATION (FROM DIST'NS) (1.4 mm BASKET)

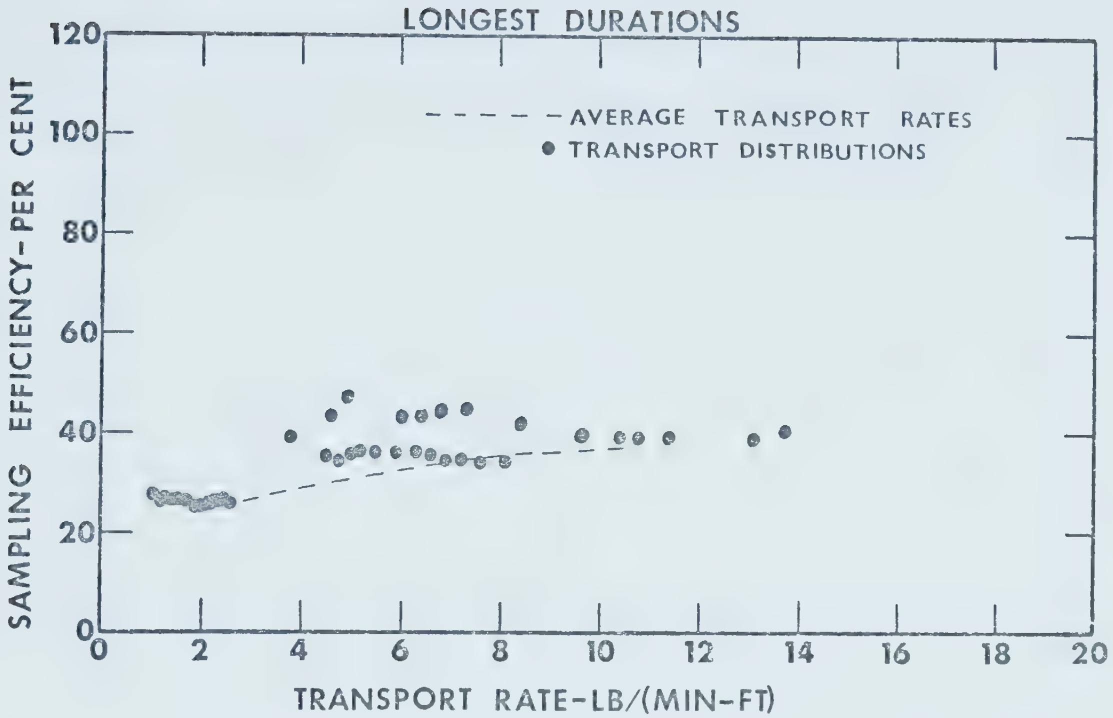


FIG. 5-4-C TRANSPORT-EFFICIENCY RELATIONS (FROM DIST'NS)
(1.4 mm BASKET)

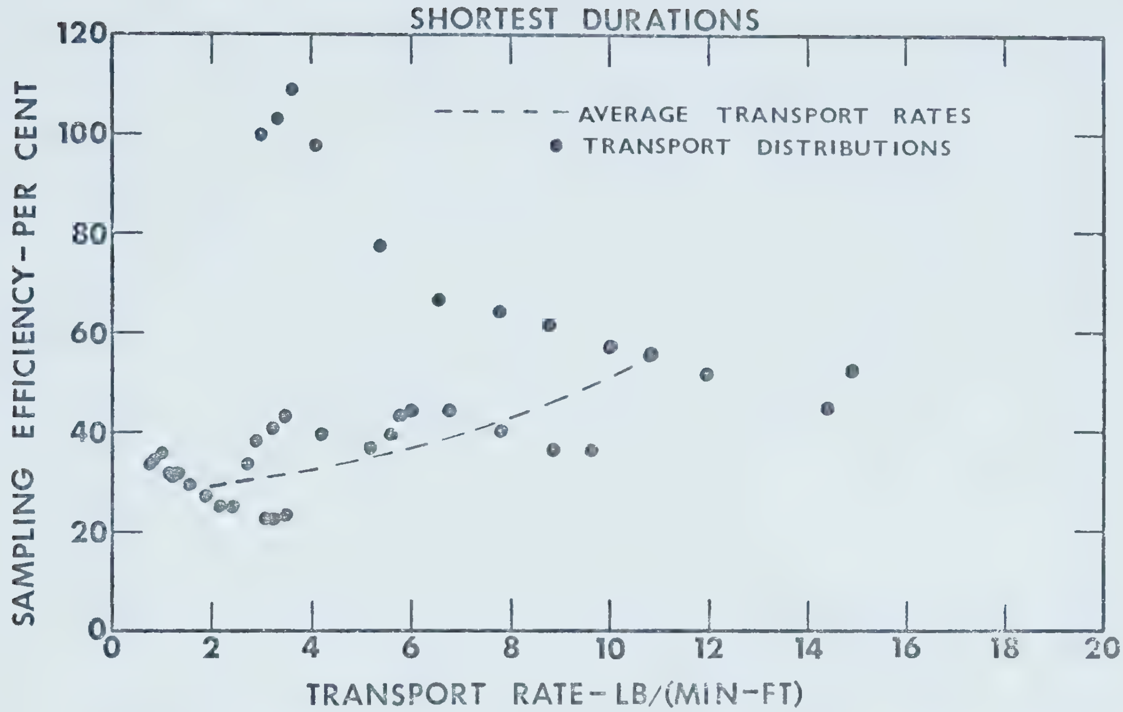


FIG. 5-5-A TRANSPORT-EFFICIENCY RELATION (FROM DIST'NS)
(2.4 mm BASKET)

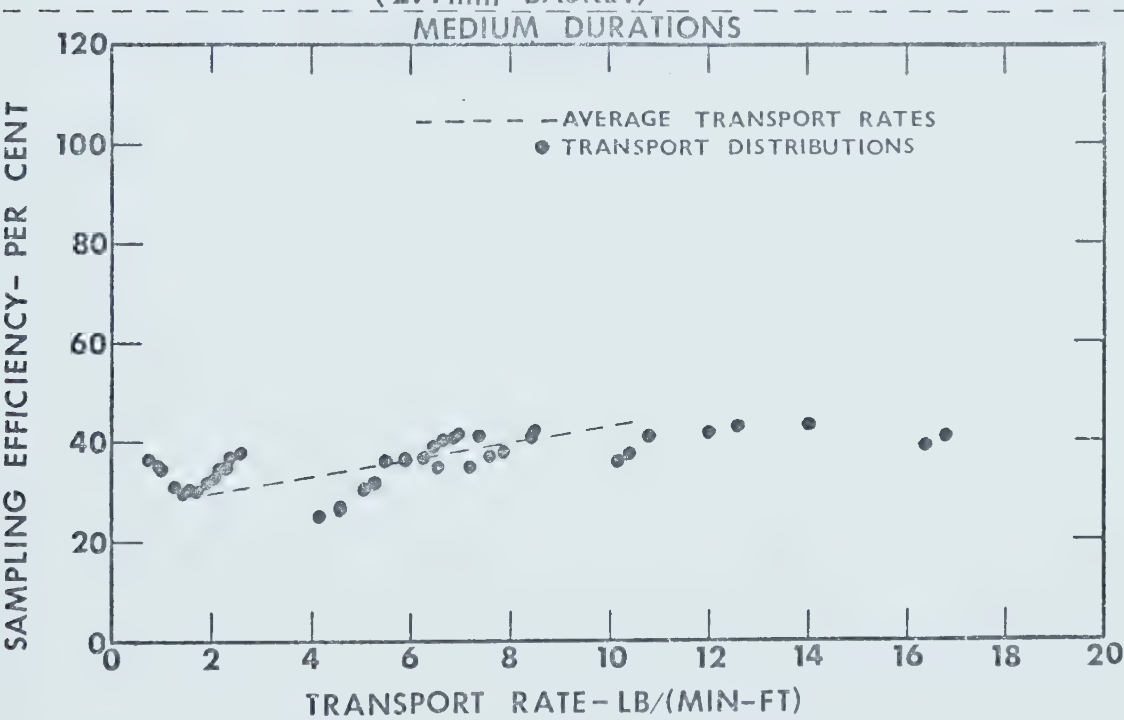


FIG. 5-5-B TRANSPORT-EFFICIENCY RELATION (FROM DIST'NS)
(2.4 mm BASKET)

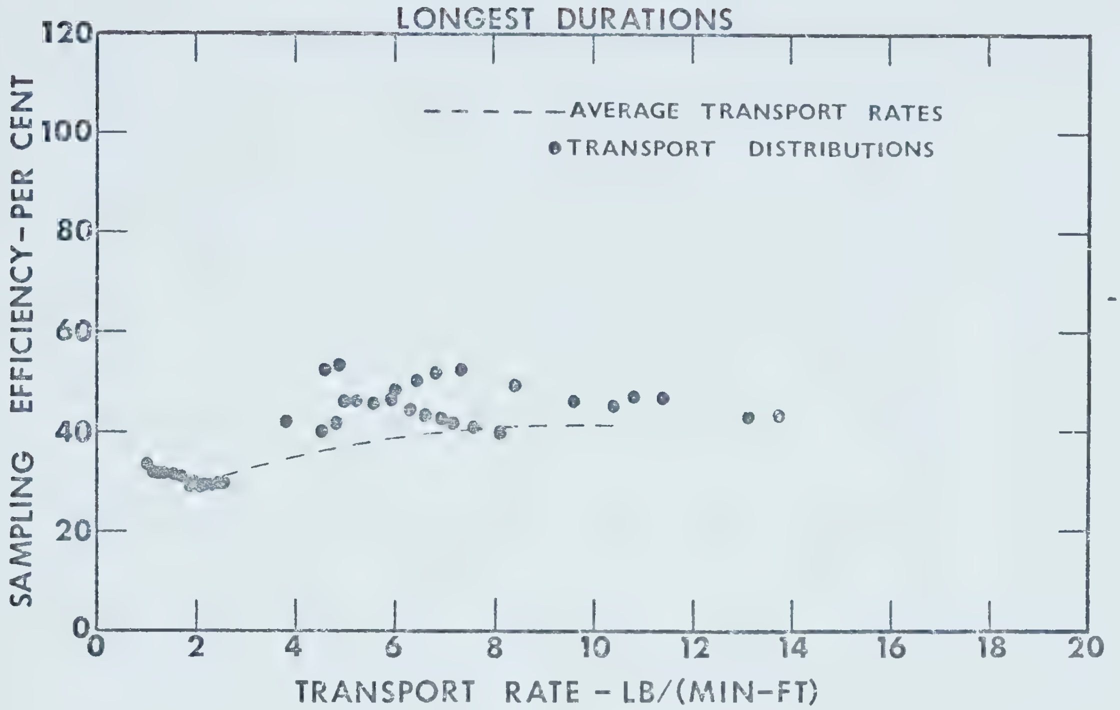


FIG. 5-5-C TRANSPORT-EFFICIENCY RELATION (FROM DIST'NS) (2.4 mm BASKET)

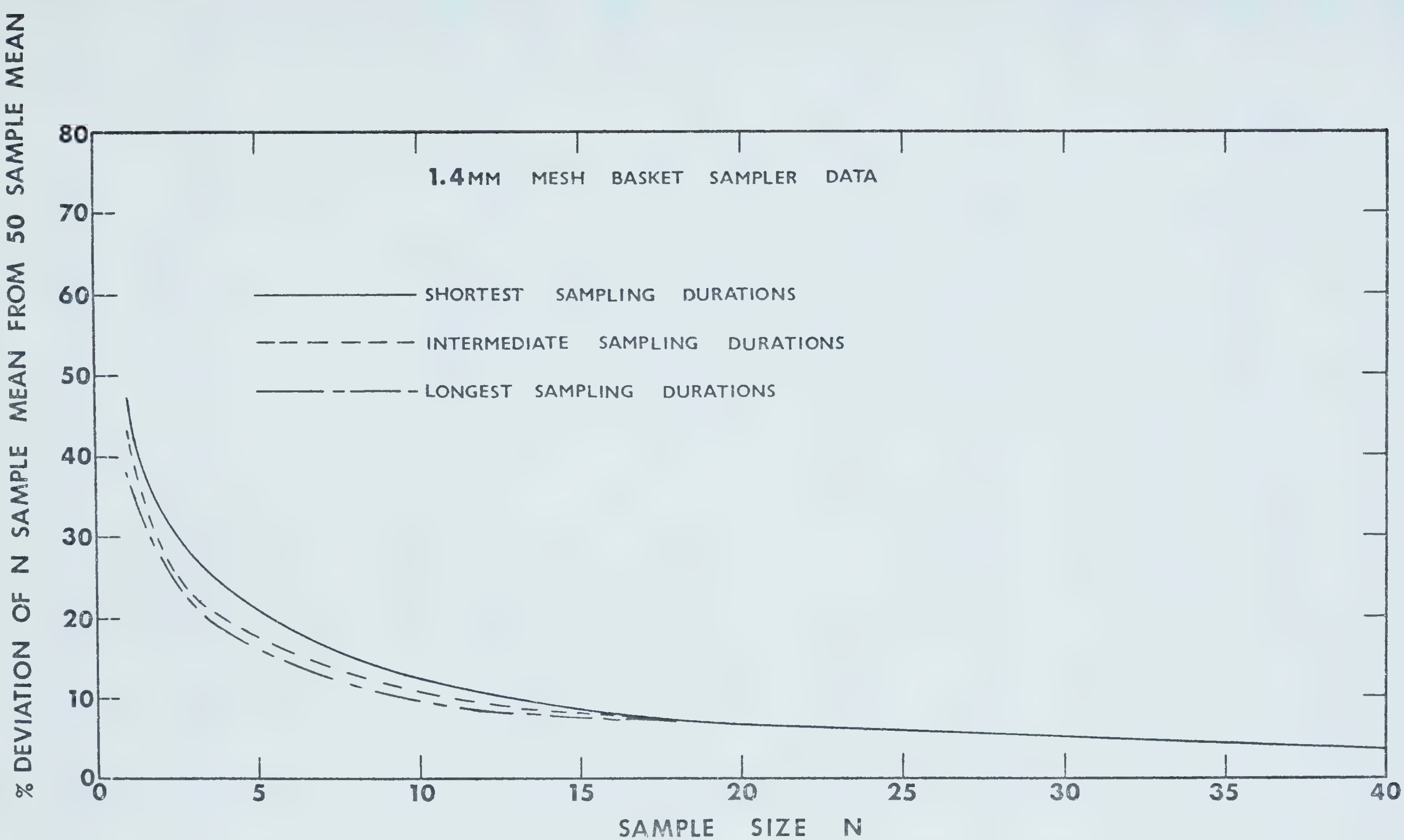


FIG. 5-6 PLOT OF THE VARIATION OF SAMPLE MEANS WITH SAMPLE SIZE

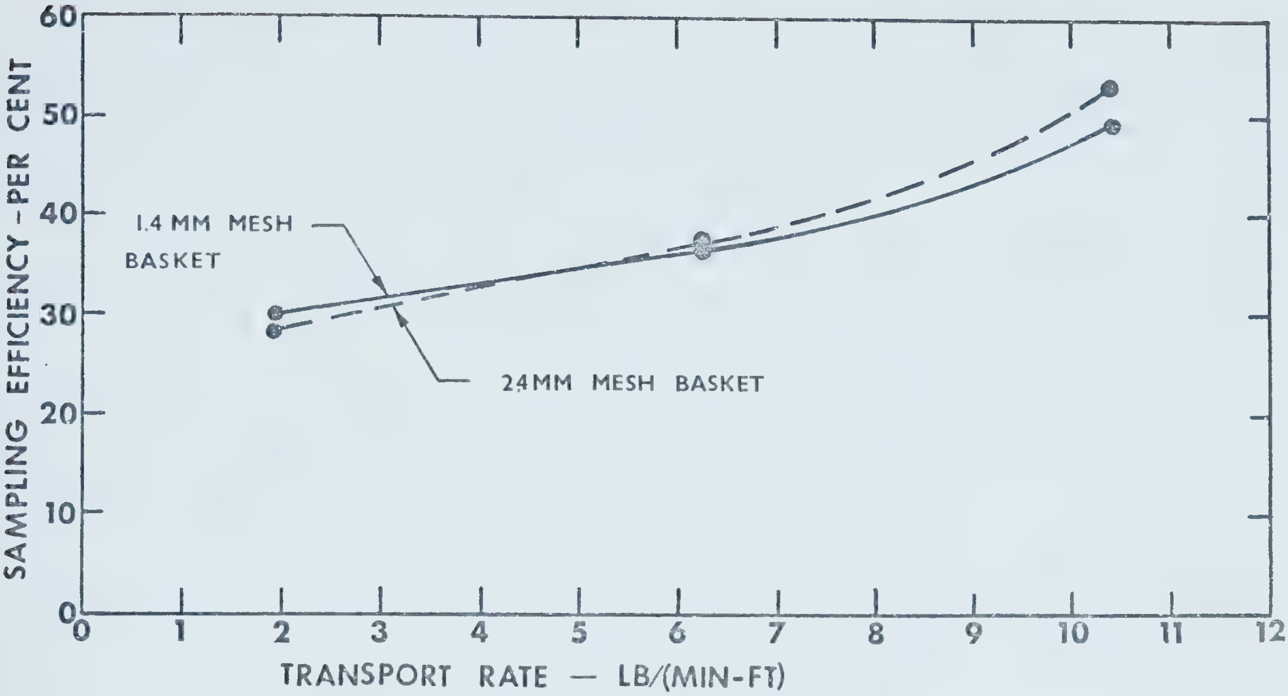


FIG. 5-7-A SAMPLING EFFICIENCY vs TRANSPORT RATE (MODEL)

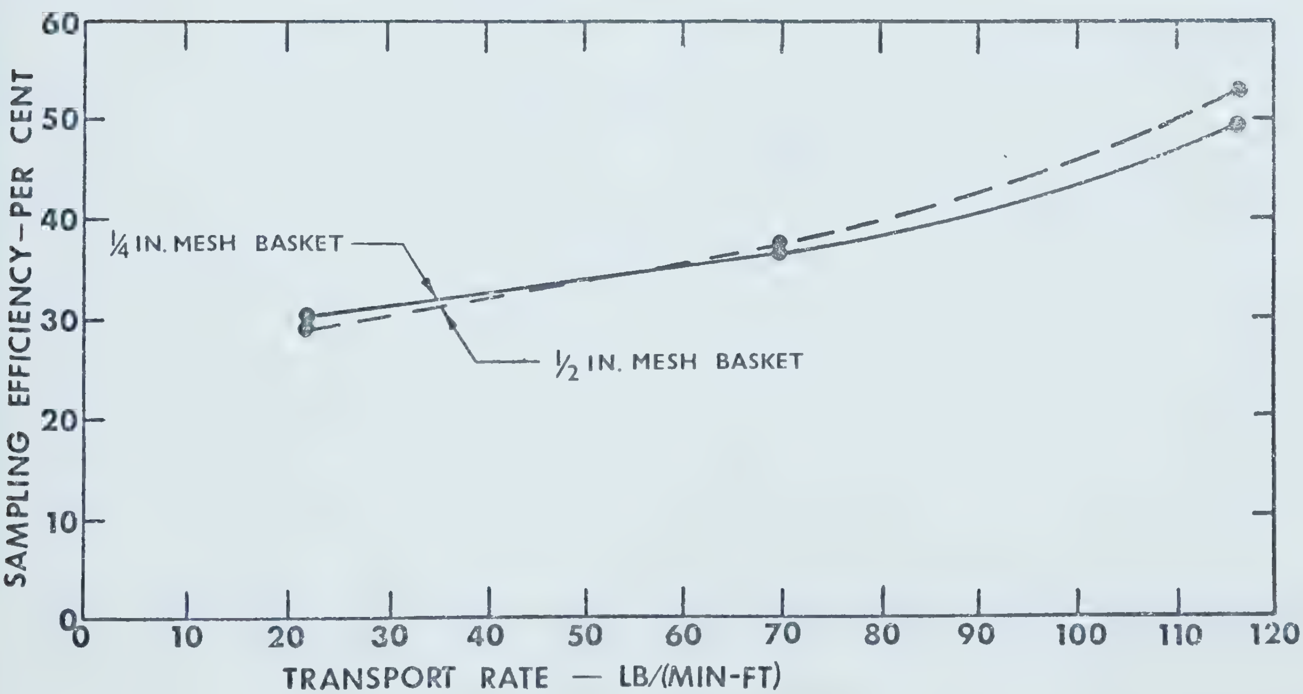


FIG. 5-7-B SAMPLING EFFICIENCY vs TRANSPORT RATE (PROTOTYPE)

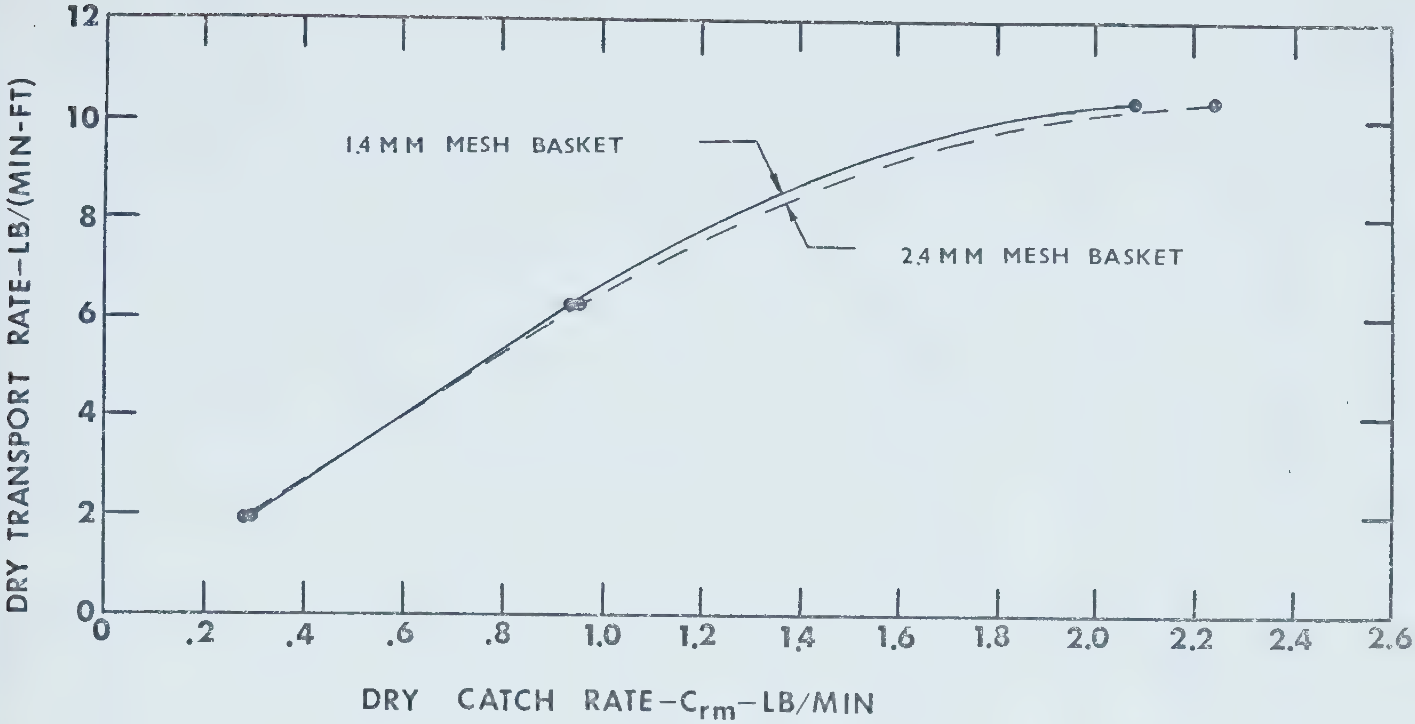


FIG. 5-8-A TRANSPORT RATE vs SAMPLER CATCH RATE (MODEL)

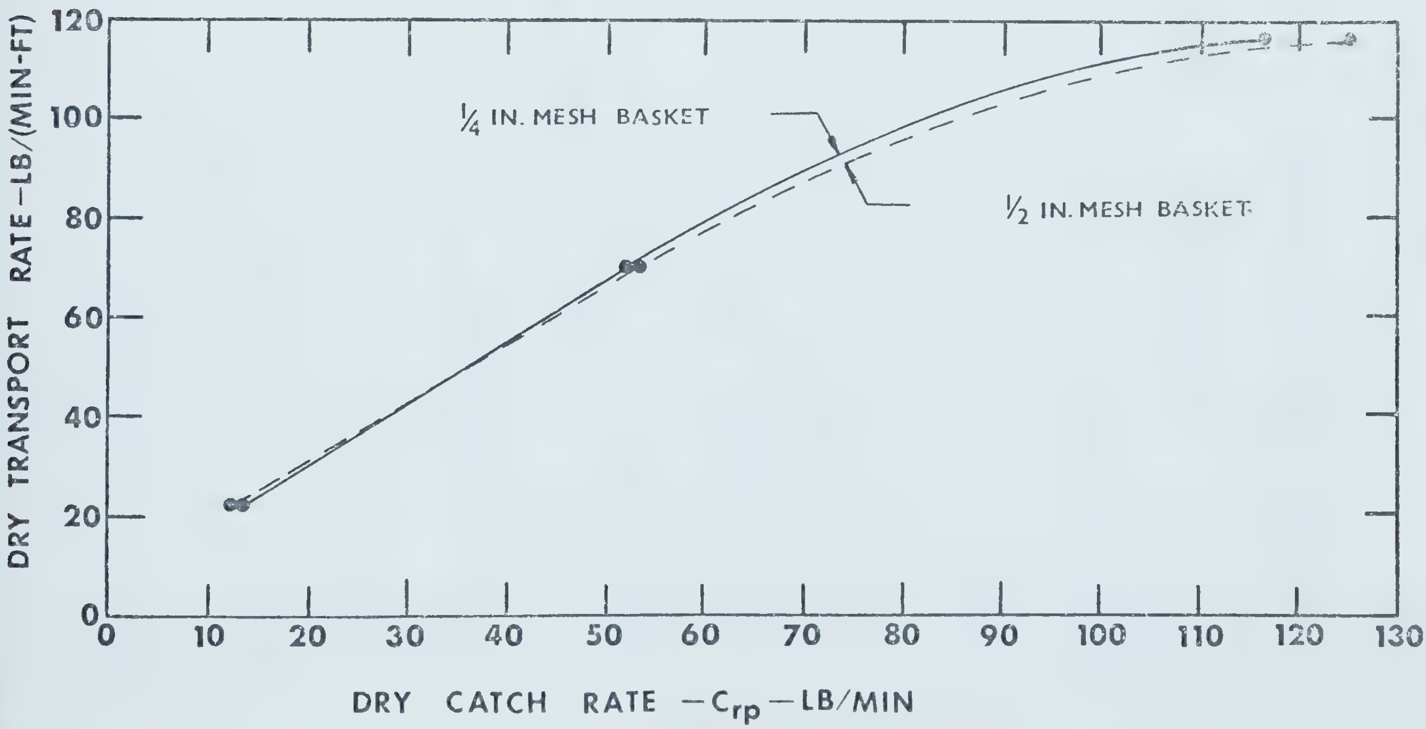


FIG. 5-8-B TRANSPORT RATE vs SAMPLER CATCH RATE (PROTOTYPE)

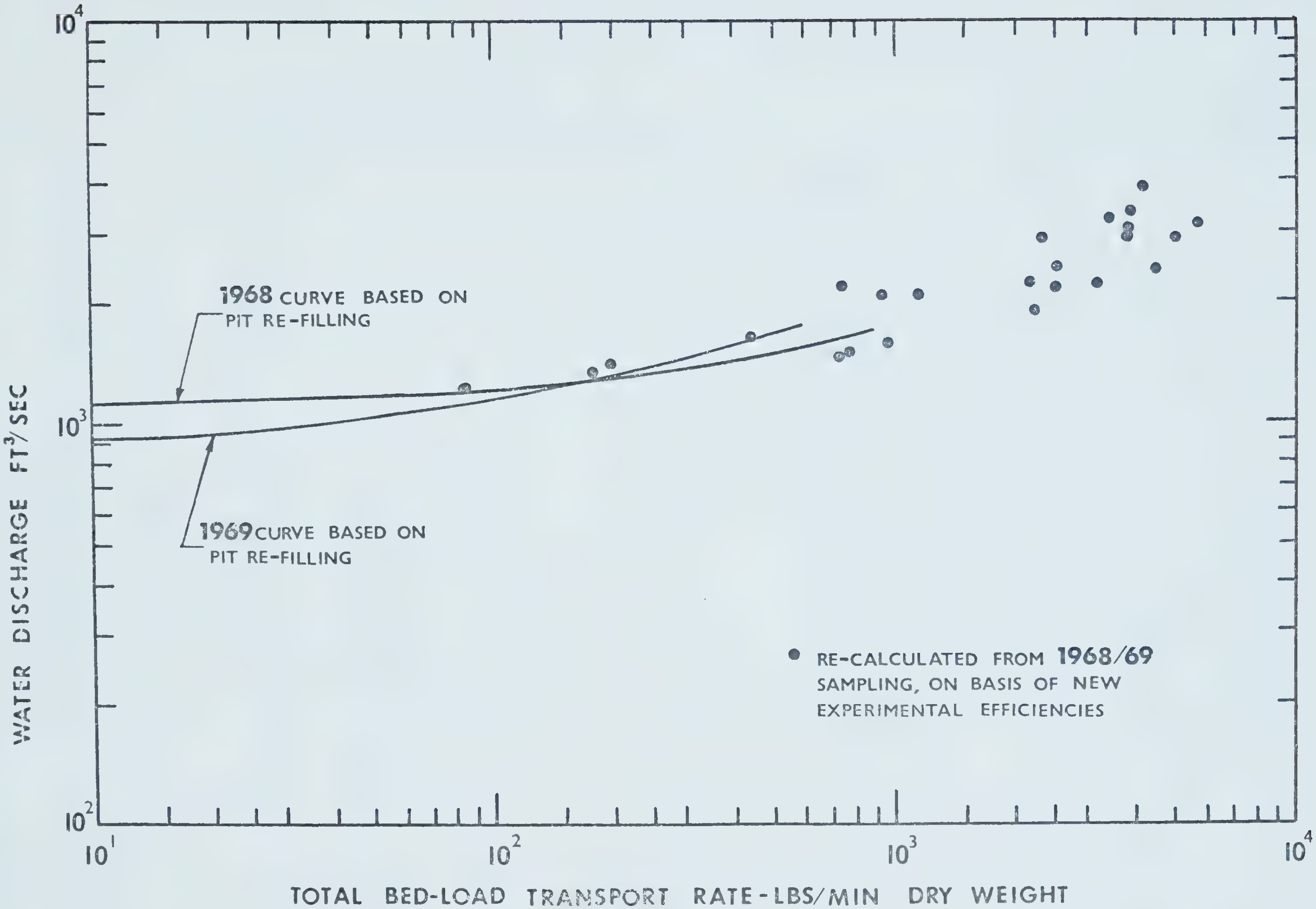
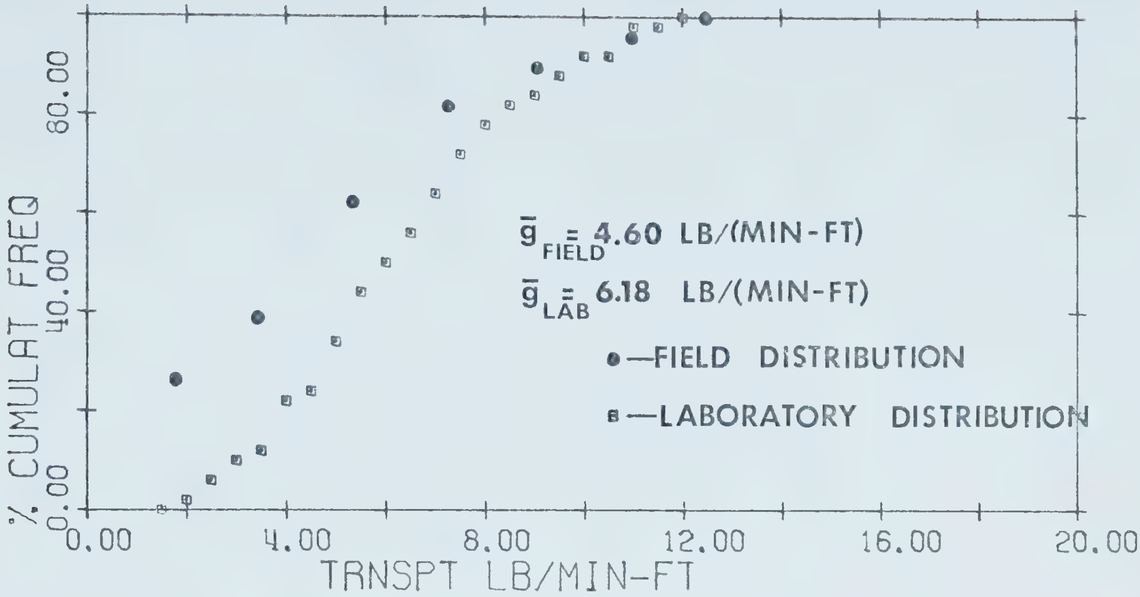


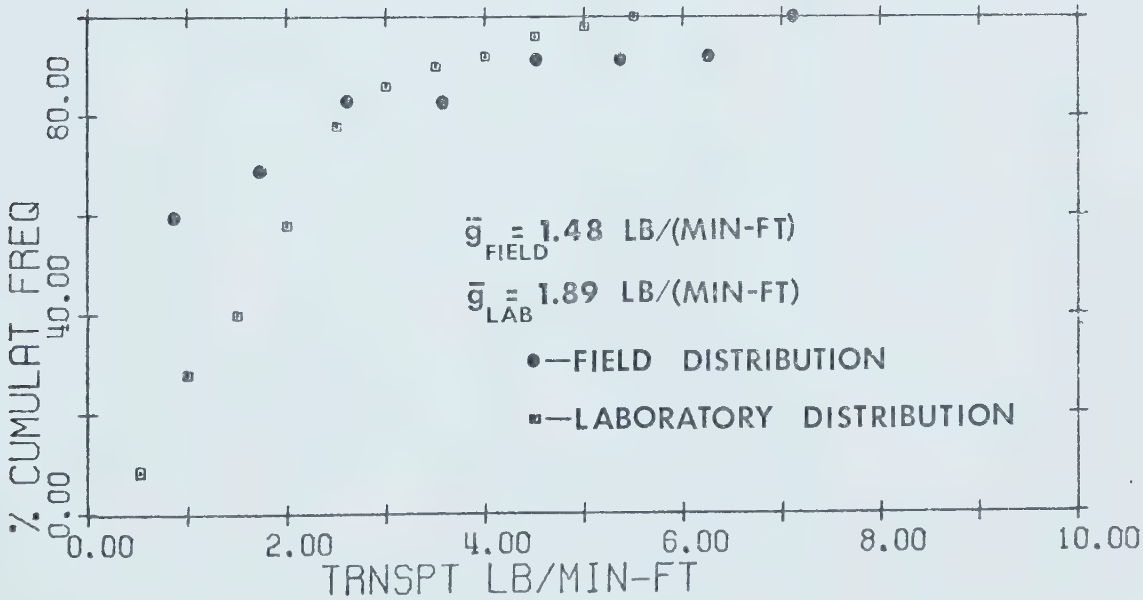
FIG.5-9 BED-LOAD RATING PLOT FOR THE ELBOW RIVER AT BRAGG CREEK



CUMULATIVE FREQUENCY DIAGRAM

LAB FLOW CONDITION NO. 1- SAMPLING DURATION=60 SEC
FIELD DISCHARGE RANGE=2200-2400 CFS

A



CUMULATIVE FREQUENCY DIAGRAM

LAB FLOW CONDITION NO.2- SAMPLING DURATION=120 SEC
FIELD DISCHARGE RANGE=2000-2400 CFS

B

FIG. 5-10 FIELD AND LABORATORY TRANSPORT DISTRIBUTIONS

TABLE 3-3 MODEL AND PROTOTYPE BASKET SCREEN SIZES

(1) Prototype Basket Designation	(2) Screen Openings of Prototype Baskets mm	(3) Model Basket Designation	(4) Screen Openings of 1:5 Scale Models mm	(5) Screen Openings of Closest Wire Mesh mm
Medium - ½ in.	Top - 19.05 Sides - 12.70 Bottom - 6.36	Medium - 2.4 mm	Top - 3.81 Sides - 2.54 Bottom - 1.27	Top - 4.00 Sides - 2.38 Bottom - 1.41
Small - ¼ in.	Top - 12.70 Sides - 6.35 Bottom - 4.76	Small - 1.4 mm	Top - 2.54 Sides - 1.27 Bottom - 0.95	Top - 2.38 Sides - 1.41 Bottom - 1.00

TABLE 4-1 BED SLOPE, WATER SURFACE SLOPE AND DEPTH DATA

(1) Flow Condition No.	(2) Plot No.	(3) Bed Slope	(4) Water Surface Slope	(5) Depth of Flow ft
1	1	.0047	.0044	.59
	2	.0047	.0047	.55
	3	.0046	.0047	.61
	4	.0048	.0048	.57
	5	.0047	.0046	.59
	6	.0046	.0046	.58
	Average	.0047	.0046	.58
2	1	.0029	.0030	.55
	2	.0030	.0029	.55
	3	.0031	.0028	.56
	4	.0028	.0028	.60
	5	.0031	.0032	.58
	6	.0028	.0028	.60
	Average	.0029	.0029	.57
3	1	.0051	.0050	.55
	2	.0051	.0050	.57
	3	.0052	.0051	.55
	4	.0051	.0050	.57
	5	.0049	.0048	.59
	6	.0048	.0049	.55
	Average	.0050	.0050	.56

TABLE 4-4-A

BED-LOAD SAMPLER DATA

FLOW CONDITION #1
SAMPLER TYPE: CART SAMPLER

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 240 SEC

SAMPLE ID NUMBER	STRAIN $\frac{\mu\ IN}{IN}$	DRY SAMPLER CATCH LBS	TRANSPORT RATE LB/MIN
145001	251	24.80	24.80
145002	168	16.54	16.54
145003	380	37.64	37.64
145004	146	14.36	14.36
145005	318	31.47	31.47
145006	223	22.02	22.02
145007	321	31.77	31.77
145008	278	27.49	27.49
145009	250	24.70	24.70
145010	217	21.42	21.42
145011	296	29.28	29.28
145012	229	22.61	22.61
145013	219	21.61	21.61
145014	280	27.68	27.68
145015	218	21.51	21.51
145016	246	24.31	24.31
145017	180	17.73	17.73
145018	272	26.89	26.89
145019	236	23.31	23.31
145020	250	24.70	24.70
145021	149	14.65	14.65
145022	322	31.87	31.87
145023	296	29.28	29.28
145024	192	18.93	18.93
145025	173	17.04	17.04
		MEAN =	24.14

TABLE 4-4-B

BED-LOAD SAMPLER DATA

FLOW CONDITION #2
SAMPLER TYPE: CART SAMPLER

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 240 SEC

SAMPLE ID NUMBER	STRAIN μ IN / IN	DRY SAMPLER CATCH LBS	TRANSPORT RATE LB/MIN
245001	51	4.90	4.90
245002	63	6.10	6.10
245003	12	1.02	1.02
245004	55	5.30	5.30
245005	31	2.91	2.91
245006	48	4.60	4.60
245007	86	8.39	8.39
245008	72	6.99	6.99
245009	109	10.67	10.67
245010	119	11.66	11.66
245011	33	3.11	3.11
245012	78	7.59	7.59
245013	127	12.46	12.46
245014	89	8.68	8.68
245015	69	6.69	6.69
245016	47	4.50	4.50
245017	75	7.29	7.29
245018	71	6.89	6.89
245019	49	4.71	4.71
245020	154	15.15	15.15
245021	64	6.20	6.20
245022	27	2.51	2.51
245023	44	4.20	4.20
245024	117	11.47	11.47
245025	55	5.30	5.30
		MEAN =	6.77

TABLE 4-4-C

BED-LOAD SAMPLER DATA

FLOW CONDITION #3
SAMPLER TYPE: CART SAMPLER

SAMPLE DURATION = 20 SEC
SAMPLE INTERVAL = 240 SEC

SAMPLE ID NUMBER	STRAIN $\frac{\mu \text{ IN}}{\text{IN}}$	DRY SAMPLER CATCH LB	TRANSPORT RATE LB/MIN
342001	98	9.58	28.74
342002	119	11.66	34.98
342003	72	6.99	20.97
342004	88	8.58	25.74
342005	227	22.41	67.23
342006	144	14.15	42.45
342007	59	5.69	17.07
342008	130	12.76	38.28
342009	179	17.63	52.89
342010	152	14.95	44.85
342011	138	13.56	40.68
342012	122	11.97	35.91
342013	111	10.87	32.61
342014	125	12.26	36.78
342015	158	15.55	46.65
342016	156	15.34	46.02
342017	100	9.78	29.34
342018	161	15.85	47.55
342019	221	21.82	65.46
342020	44	4.20	12.6
342021	122	11.97	35.91
342022	148	14.55	43.65
342023	219	21.61	64.83
342024	123	12.07	36.21
342025	147	14.45	43.35
		MEAN =	39.63

TABLE 4-5-A

BED-LOAD SAMPLER DATA

FLOW CONDITION # 1
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 30 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
113001	72.	2.85	16.31
113002	72.	1.04	5.92
113003	72.	1.03	5.91
113004	72.	2.82	16.13
113005	72.	0.16	0.94
113006	72.	1.82	10.37
113007	72.	1.36	7.80
113008	73.	0.46	2.61
113009	73.	0.74	4.24
113010	73.	1.01	5.77
113011	73.	0.32	1.82
113012	73.	2.60	14.85
113013	73.	1.34	7.68
113014	73.	0.04	0.20
113015	73.	0.67	3.86
113016	74.	0.48	2.77
113017	74.	0.72	4.09
113018	74.	0.91	5.20
113019	74.	1.10	6.27
113020	68.	2.26	12.94
113021	68.	0.50	2.84
113022	68.	0.23	1.32
113023	68.	0.57	3.25
113024	69.	2.07	11.85
113025	69.	1.61	9.19
113026	69.	1.05	6.00
113027	69.	1.99	11.37
113028	69.	0.14	0.81
113029	69.	0.57	3.28
113030	69.	0.47	2.71
113031	69.	0.83	4.75
113032	70.	0.18	1.02
113033	70.	1.58	9.04
113034	70.	0.97	5.57
113035	70.	0.61	3.47
113036	70.	0.49	2.80
113037	70.	1.55	8.86
113038	70.	2.03	11.58
113039	70.	0.56	3.19
113040	70.	1.04	5.97
113041	71.	0.20	1.14
113042	71.	1.56	8.94
113043	71.	1.05	5.98
113044	71.	2.40	13.69
113045	71.	0.99	5.68
113046	71.	2.26	12.90
113047	71.	0.47	2.69
113048	71.	1.14	6.53
113049	72.	1.37	7.81
113050	72.	0.26	1.4[illegible]

MEAN = 6.23

TABLE 4-5-B BED-LOAD SAMPLER DATA

FLOW CONDITION # 1
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 45 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
114001	72.	3.66	13.95
114002	72.	0.70	2.67
114003	72.	1.68	6.39
114004	72.	3.29	12.53
114005	72.	0.66	2.52
114006	72.	1.44	5.47
114007	72.	1.50	5.71
114008	72.	1.78	6.77
114009	73.	0.73	2.77
114010	73.	1.87	7.14
114011	73.	1.09	4.16
114012	73.	1.73	6.61
114013	73.	0.37	1.40
114014	70.	3.35	12.76
114015	70.	1.58	6.00
114016	70.	1.41	5.39
114017	71.	2.02	7.71
114018	71.	1.60	6.10
114019	71.	1.87	7.14
114020	71.	2.30	8.75
114021	71.	1.36	5.18
114022	72.	1.76	6.69
114023	72.	1.08	4.13
114024	72.	1.78	6.76
114025	72.	1.64	6.25
114026	72.	1.25	4.75
114027	72.	1.73	6.58
114028	73.	1.76	6.72
114029	73.	1.39	5.28
114030	73.	2.19	8.35
114031	73.	1.79	6.83
114032	73.	1.29	4.91
114033	73.	1.13	4.32
114034	74.	0.95	3.61
114035	74.	1.92	7.30
114036	74.	2.14	8.15
114037	74.	2.49	9.50
114038	74.	2.88	10.96
114039	74.	1.57	5.99
114040	70.	0.79	2.99
114041	70.	0.63	2.39
114042	70.	1.14	4.33
114043	70.	1.40	5.34
114044	71.	2.55	9.73
114045	71.	1.48	5.63
114046	71.	1.74	6.65
114047	71.	3.19	12.16
114048	71.	1.44	5.50
114049	72.	0.34	1.31
114050	72.	2.26	8.59

MEAN=6.38

TABLE 4-5-C BED-LOAD SAMILER DATA

FLOW CONDITION # 1
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
115001	68.	2.17	6.21
115002	68.	3.08	8.81
115003	68.	2.47	7.04
115004	68.	1.81	5.18
115005	68.	2.50	7.14
115006	68.	4.12	11.77
115007	69.	3.17	9.06
115008	69.	2.70	7.71
115009	69.	1.89	5.39
115010	69.	2.43	6.95
115011	69.	2.00	5.72
115012	69.	1.77	5.06
115013	70.	2.21	6.31
115014	70.	3.72	10.62
115015	70.	2.28	6.51
115016	70.	0.99	2.82
115017	70.	2.87	8.21
115018	70.	0.90	2.57
115019	71.	1.40	3.99
115020	71.	1.35	3.87
115021	71.	2.51	7.18
115022	71.	0.75	2.15
115023	72.	2.28	6.52
115024	72.	0.71	2.02
115025	72.	1.59	4.55
115026	72.	1.17	3.34
115027	72.	2.19	6.25
115028	72.	2.65	7.58
115029	72.	1.25	3.58
115030	72.	1.40	4.01
115031	73.	2.84	8.11
115032	73.	0.62	1.77
115033	73.	3.74	10.69
115034	73.	1.36	3.89
115035	73.	3.20	9.14
115036	73.	1.88	5.36
115037	73.	2.03	5.80
115038	74.	1.73	4.94
115039	74.	1.23	3.52
115040	74.	3.44	9.83
115041	74.	1.65	4.71
115042	74.	2.46	7.04
115043	74.	1.75	5.00
115044	75.	2.36	6.75
115045	75.	3.47	9.91
115046	75.	3.81	10.88
115047	75.	1.88	5.36
115048	75.	2.64	7.54
115049	75.	1.65	4.72
115050	76.	2.07	5.92
			MEAN=6.18

TABLE 4-5-D BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
215001	77.	0.09	0.25
215002	77.	0.10	0.28
215003	77.	0.41	1.19
215004	77.	1.18	3.38
215005	77.	1.05	3.01
215006	77.	1.77	5.04
215007	77.	0.27	0.78
215008	78.	0.62	1.77
215009	78.	0.15	0.43
215010	78.	1.51	4.32
215011	78.	1.39	3.97
215012	78.	0.97	2.77
215013	78.	1.25	3.56
215014	78.	0.37	1.04
215015	78.	0.16	0.46
215016	78.	0.23	0.67
215017	79.	0.14	0.40
215018	79.	0.42	1.19
215019	79.	0.70	2.00
215020	79.	1.13	3.24
215021	79.	3.11	8.87
215022	79.	0.83	2.36
215023	79.	0.29	0.82
215024	79.	1.05	3.01
215025	79.	0.01	0.02
215026	80.	1.21	3.46
215027	80.	0.82	2.35
215028	80.	1.30	3.71
215029	80.	0.47	1.35
215030	80.	0.15	0.42
215031	75.	0.44	1.26
215032	75.	1.30	3.70
215033	75.	0.54	1.55
215034	75.	0.49	1.40
215035	75.	0.27	0.76
215036	76.	0.74	2.12
215037	76.	0.16	0.44
215038	76.	1.25	3.56
215039	76.	0.69	1.97
215040	76.	0.11	0.32
215041	76.	0.45	1.30
215042	76.	1.18	3.36
215043	76.	0.49	1.41
215044	76.	0.42	1.19
215045	77.	1.66	4.74
215046	77.	1.29	3.67
215047	77.	0.65	1.84
215048	77.	0.25	0.71
215049	77.	0.47	1.35
215050	77.	0.80	2.28

MEAN= 2.10

TABLE 4-5-E

BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 120 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
216001	75.	2.05	2.93
216002	75.	1.38	1.97
216003	75.	0.38	0.54
216004	75.	1.47	2.10
216005	75.	1.28	1.82
216006	76.	2.85	4.08
216007	76.	1.35	1.93
216008	76.	1.06	1.52
216009	76.	0.90	1.29
216010	76.	0.25	0.35
216011	76.	1.47	2.10
216012	76.	1.34	1.91
216013	77.	1.27	1.81
216014	77.	0.33	0.47
216015	77.	0.67	0.96
216016	77.	2.01	2.87
216017	68.	0.67	0.96
216018	68.	2.01	2.87
216019	68.	1.54	2.19
216020	69.	1.73	2.47
216021	69.	1.82	2.59
216022	69.	0.37	0.53
216023	69.	0.28	0.40
216024	69.	0.82	1.16
216025	70.	0.39	0.55
216026	70.	0.62	0.89
216027	71.	2.48	3.54
216028	71.	1.63	2.33
216029	71.	1.41	2.01
216030	71.	2.82	4.03
216031	71.	1.52	2.17
216032	71.	0.41	0.58
216033	72.	1.41	2.01
216034	72.	1.70	2.43
216035	72.	3.83	5.47
216036	72.	3.33	4.76
216037	72.	0.76	1.08
216038	73.	2.21	3.15
216039	73.	0.59	0.84
216040	73.	0.95	1.35
216041	73.	1.45	2.07
216042	73.	0.94	1.34
216043	74.	1.05	1.49
216044	74.	2.45	3.50
216045	74.	0.56	0.80
216046	76.	1.32	1.88
216047	76.	0.43	0.61
216048	76.	0.24	0.34
216049	77.	1.25	1.78
216050	77.	1.31	1.83

MEAN=1.89

TABLE 4-5-F BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 180 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
217001	67.	2.55	2.43
217002	67.	3.32	3.16
217003	68.	2.20	2.10
217004	68.	2.53	2.41
217005	68.	0.95	0.90
217006	69.	2.50	2.38
217007	69.	2.20	2.10
217008	69.	2.18	2.07
217009	70.	3.17	3.02
217010	70.	1.04	0.99
217011	70.	0.91	0.87
217012	71.	2.17	2.07
217013	71.	1.34	1.27
217014	71.	2.58	2.46
217015	72.	2.49	2.37
217016	72.	2.45	2.33
217017	72.	2.34	2.23
217018	73.	0.49	0.47
217019	73.	1.03	0.98
217020	73.	1.95	1.86
217021	74.	1.19	1.13
217022	74.	1.78	1.70
217023	76.	1.63	1.55
217024	76.	1.94	1.85
217025	76.	3.81	3.63
217026	76.	2.52	2.40
217027	77.	1.87	1.78
217028	77.	0.51	0.49
217029	77.	1.20	1.15
217030	77.	1.43	1.36
217031	77.	1.26	1.20
217032	77.	0.98	0.94
217033	77.	2.76	2.63
217034	78.	1.74	1.66
217035	78.	4.93	4.69
217036	78.	2.81	2.68
217037	78.	2.91	2.77
217038	78.	1.16	1.10
217039	78.	2.78	2.64
217040	79.	1.27	1.21
217041	79.	0.40	0.38
217042	79.	0.55	0.52
217043	79.	1.40	1.33
217044	79.	2.07	1.97
217045	79.	4.39	4.18
217046	79.	1.34	1.27
217047	80.	3.15	3.00
217048	80.	1.17	1.11
217049	80.	3.06	2.91
217050	80.	1.64	1.56

MEAN=1.90

TABLE 4-5-G BED-LOAD SAMPLER DATA

FLOW CONDITION # 3 SAMPLE DURATION = 10 SEC
SAMPLER TYPE : SLICE SAMPLER SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
311001	78.	0.74	12.71
311002	78.	0.05	0.81
311003	78.	0.05	0.81
311004	78.	0.43	7.34
311005	78.	1.53	26.23
311006	78.	1.10	18.78
311007	79.	1.20	20.58
311008	79.	0.22	3.74
311009	79.	0.85	14.54
311010	79.	1.45	24.82
311011	79.	0.18	3.04
311012	79.	0.39	6.74
311013	79.	0.16	2.75
311014	79.	0.59	10.17
311015	79.	0.32	5.51
311016	79.	1.84	31.56
311017	79.	0.20	3.35
311018	79.	0.51	8.82
311019	79.	0.13	2.22
311020	80.	0.27	4.59
311021	80.	0.10	1.66
311022	80.	0.15	2.65
311023	80.	0.85	14.65
311024	80.	0.69	11.83
311025	80.	0.15	2.51
311026	80.	0.22	3.74
311027	80.	0.60	10.34
311028	80.	1.06	18.21
311029	80.	0.64	10.94
311030	80.	0.51	8.72
311031	80.	1.75	29.93
311032	80.	0.57	9.85
311033	81.	0.69	11.79
311034	81.	0.18	3.04
311035	81.	0.07	1.27
311036	81.	1.02	17.47
311037	81.	0.86	14.72
311038	81.	0.01	0.21
311039	81.	0.38	6.53
311040	81.	0.33	5.61
311041	81.	0.22	3.71
311042	81.	0.28	4.73
311043	81.	1.59	27.22
311044	81.	0.62	10.55
311045	82.	0.22	3.74
311046	82.	0.18	3.14
311047	82.	0.82	14.01
311048	82.	0.47	8.01
311049	82.	0.43	7.41
311050	82.	0.82	14.05

MEAN=9.83

FLOW CONDITION # 3
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 20 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
312001	70.	0.72	6.21
312002	70.	2.36	20.21
312003	70.	2.28	19.57
312004	70.	1.98	17.00
312005	71.	0.26	2.21
312006	71.	2.41	20.63
312007	71.	2.26	19.31
312008	71.	2.18	18.66
312009	72.	0.88	7.57
312010	72.	2.00	17.10
312011	72.	1.27	10.89
312012	72.	1.99	17.05
312013	72.	1.43	12.23
312014	72.	0.56	4.84
312015	72.	1.59	13.63
312016	72.	1.21	10.34
312017	73.	0.86	7.41
312018	73.	1.29	11.07
312019	73.	0.93	7.96
312020	73.	3.41	29.19
312021	73.	0.88	7.55
312022	73.	1.27	10.87
312023	73.	0.95	8.15
312024	73.	1.41	12.05
312025	74.	0.29	2.51
312026	74.	0.94	8.08
312027	74.	1.67	14.28
312028	74.	0.97	8.28
312029	74.	2.25	19.31
312030	74.	1.87	16.06
312031	74.	0.55	4.75
312032	74.	0.92	7.92
312033	75.	2.61	22.40
312034	75.	1.96	16.82
312035	75.	1.17	10.04
312036	75.	1.02	8.77
312037	75.	1.28	11.00
312038	77.	3.86	33.11
312039	77.	0.74	6.37
312040	77.	0.75	6.41
312041	77.	1.51	12.92
312042	77.	0.50	4.25
312043	77.	0.83	7.15
312044	78.	0.88	7.50
312045	78.	0.16	1.38
312046	78.	0.51	4.38
312047	78.	1.31	11.19
312048	78.	1.27	10.89
312049	78.	0.31	2.65
312050	78.	1.46	12.53

MEAN=11.65

FLOW CONDITION # 3
SAMPLER TYPE : SLICE SAMPLER

SAMPLE DURATION = 30 SEC
SAMPLE INTERVAL = 180 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
313001	63.	2.91	16.63
313002	68.	1.11	6.34
313003	69.	0.71	4.08
313004	69.	3.42	19.56
313005	69.	0.25	1.44
313006	69.	1.98	11.30
313007	69.	1.68	9.61
313008	70.	1.53	8.72
313009	70.	2.79	15.96
313010	70.	2.37	13.52
313011	70.	2.29	13.08
313012	71.	0.63	3.62
313013	71.	1.28	7.34
313014	71.	1.15	6.59
313015	71.	1.82	10.39
313016	72.	0.86	4.89
313017	72.	1.65	9.41
313018	72.	1.91	10.91
313019	74.	1.10	6.31
313020	70.	2.33	13.30
313021	70.	0.80	4.57
313022	70.	1.80	10.28
313023	70.	1.53	8.77
313024	71.	1.10	6.28
313025	71.	5.17	29.53
313026	71.	0.68	3.89
313027	71.	1.92	10.97
313028	71.	1.35	7.74
313029	71.	2.88	16.46
313030	72.	2.11	12.08
313031	72.	0.56	3.20
313032	72.	3.66	20.93
313033	72.	0.91	5.18
313034	72.	2.32	13.25
313035	72.	1.65	9.44
313036	73.	0.96	5.49
313037	73.	0.85	4.85
313038	73.	0.85	4.86
313039	73.	2.60	14.86
313040	73.	0.31	1.79
313041	73.	1.13	6.47
313042	73.	0.73	4.15
313043	74.	0.74	4.20
313044	74.	3.30	18.89
313045	74.	1.19	6.80
313046	74.	4.57	26.09
313047	74.	1.82	10.40
313048	75.	1.16	6.62
313049	75.	0.55	3.14
313050	75.	1.96	11.18

MEAN=9.71

TABLE 4-7 SUMMARY OF FLOW DATA

(A) Measured Values

Flow Condition No. (1)	Discharge Q (2)	Depth of Flow h (3)	Bed Slope S_b (4)	Water Surface Slope S_w (5)	Median Grain Size D_{50} (6)	MEAN VELOCITY (7) X-Sect. Average ft/sec V (a)	Centre-line ft/sec $V_{\mathbb{C}}$ (b)	MEAN TRANSPORT (8) X-Sect. Average lb/(min-ft) g_s (a)	Centre-line lb/(min-ft) g_s (b)
1	6.0	0.58	0.0047	0.0046	5.3	2.60	3.34	6.59	6.76
2	5.6	0.57	0.0029	0.0029	4.3	2.47	2.78	1.85	2.12
3	7.0	0.56	0.0050	0.0050	4.2	3.14	3.57	10.62	11.23

(B) Calculated Parameters

Flow Condition No. (1)	Depth to Grain Size Ratio $\frac{h}{D_{50}}$ (2)	Froude Number (3) X-Sect Average $\frac{V^2}{gh}$ (a)	Centre-line $\frac{V_{\mathbb{C}}^2}{gh}$ (b)	Densimetric Froude Number (4) X-Sect Average $\frac{\rho_f V^2}{\gamma_b' h}$ (a)	Centre-line $\frac{\rho_f V_{\mathbb{C}}^2}{\gamma_b' h}$ (b)	Bed-load Concentration (5) X-Sect. Average C (a)	Centre-line $C_{\mathbb{C}}$ (b)
1	33.4	0.36	0.60	0.22	0.37	1160.5	932.0
2	40.4	0.33	0.42	0.21	0.26	348.7	357.3
3	40.6	0.55	0.71	0.34	0.44	1633.1	1500.3

TABLE 4-8-A BED-LOAD SAMPLER DATA

FLOW CONDITION # 1 SAMPLE DURATION = 30 SEC
SAMPLER TYPE : 1.4MM MSH BASKET SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
123001	72.	0.19	0.94
123002	72.	0.09	0.44
123003	72.	0.16	0.80
123004	72.	0.40	1.97
123005	72.	0.65	3.17
123006	73.	0.27	1.34
123007	73.	0.12	0.59
123008	73.	0.59	2.87
123009	73.	0.63	3.08
123010	73.	0.44	2.13
123011	73.	0.44	2.13
123012	73.	0.50	2.45
123013	73.	0.15	0.75
123014	73.	0.97	4.77
123015	73.	0.23	1.12
123006	74.	0.83	4.06
123017	74.	0.34	1.65
123018	74.	0.34	1.66
123019	74.	0.56	2.73
123020	74.	0.65	3.21
123021	74.	0.36	1.79
123022	74.	0.96	4.73
123023	74.	0.35	1.71
123024	74.	0.39	1.91
123025	74.	0.44	2.17
123026	75.	0.35	1.70
123027	75.	0.49	2.38
123028	75.	0.47	2.32
123029	75.	0.10	0.49
123030	75.	0.09	0.46
123031	75.	0.70	3.45
123032	75.	0.29	1.42
123033	75.	0.30	1.49
123034	75.	0.72	3.52
123035	75.	1.28	6.26
123036	76.	0.52	2.56
123037	76.	0.48	2.36
123038	76.	0.47	2.32
123039	76.	0.41	2.00
123040	76.	0.16	0.81
123041	76.	0.76	3.73
123042	76.	0.39	1.90
123043	76.	0.71	3.48
123044	76.	0.24	1.18
123045	76.	0.64	3.14
123046	77.	0.35	1.70
123047	77.	0.81	3.96
123048	77.	0.61	3.01
123049	77.	0.70	3.41
123050	77.	0.48	2.35

MEAN=**2.31**

TABLE 4-8-B BED-LOAD SAMPLER DATA

FLOW CONDITION # 1 SAMPLE DURATION = 45 SEC
SAMPLER TYPE : 1.4MM MSH BASKET SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
124001	70.	0.88	2.88
124002	70.	0.25	0.82
124003	70.	0.19	0.63
124004	70.	1.16	3.79
124005	70.	0.60	1.97
124006	70.	0.59	1.94
124007	70.	0.91	2.99
124008	70.	0.22	0.72
124009	70.	0.58	1.88
124010	70.	0.57	1.86
124011	70.	0.49	1.61
124012	71.	1.22	3.98
124013	71.	0.43	1.41
124014	71.	0.62	2.04
124015	71.	0.28	0.92
124016	71.	1.44	4.70
124017	71.	0.66	2.15
124018	71.	0.45	1.48
124019	71.	1.14	3.74
124020	71.	0.53	1.72
124021	71.	1.00	3.27
124022	72.	1.10	3.59
124023	72.	0.73	2.40
124024	72.	0.83	2.70
124025	72.	0.74	2.41
124026	72.	0.47	1.53
124027	72.	0.76	2.50
124028	72.	1.06	3.45
124029	72.	0.94	3.07
124030	72.	0.38	1.23
124031	72.	0.66	2.17
124032	73.	0.61	2.00
124033	73.	0.31	1.01
124034	73.	0.73	2.38
124035	73.	0.88	2.87
124036	73.	1.20	3.92
124037	73.	0.22	0.73
124038	73.	1.14	3.72
124039	73.	0.56	1.82
124040	73.	0.46	1.50
124041	73.	0.19	0.62
124042	73.	0.52	1.71
124043	74.	0.67	2.19
124044	74.	0.86	2.81
124045	74.	1.66	5.43
124046	74.	0.44	1.45
124047	74.	0.23	0.74
124048	74.	0.94	3.06
124049	74.	0.30	0.99
124050	74.	1.14	3.74
			MEAN=2.28

FLOW CONDITION # 1
SAMPLER TYPE : 1.4MM MSH BASKET

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
125001	73.	1.05	2.57
125002	73.	1.03	2.53
125003	73.	1.24	3.04
125004	73.	0.48	1.17
125005	73.	0.80	1.96
125006	73.	0.93	2.28
125007	73.	0.86	2.10
125008	74.	1.43	3.49
125009	74.	0.61	1.49
125010	74.	1.29	3.15
125011	74.	0.63	1.54
125012	74.	0.67	1.63
125013	74.	1.11	2.72
125014	74.	0.66	1.62
125015	74.	0.21	0.52
125016	75.	0.73	1.78
125017	75.	0.96	2.36
125018	75.	1.51	3.70
125019	75.	0.66	1.61
125020	75.	0.88	2.15
125021	75.	0.93	2.28
125022	75.	0.79	1.93
125023	75.	0.72	1.77
125024	75.	0.41	1.00
125025	76.	0.63	1.55
125026	76.	1.20	2.95
125027	76.	0.85	2.07
125028	76.	0.73	1.79
125029	76.	1.47	3.61
125030	76.	0.10	0.25
125031	76.	0.98	2.39
125032	76.	1.00	2.46
125033	76.	1.24	3.03
125034	77.	0.55	1.35
125035	77.	0.16	0.38
125036	77.	1.22	3.00
125037	77.	1.05	2.58
125038	77.	1.17	2.86
125039	77.	1.13	2.77
125040	77.	0.99	2.43
125041	77.	0.49	1.19
125042	77.	0.88	2.15
125043	78.	1.01	2.47
125044	78.	0.78	1.90
125045	78.	0.95	2.33
125046	78.	0.33	0.80
125047	78.	0.94	2.31
125048	78.	1.10	2.71
125049	78.	0.65	1.59
125050	78.	0.33	0.82
			MEAN=2.08

TABLE 4-8-D BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : 1.4MM MSH BASKET

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
225001	70.	0.15	0.36
225002	70.	0.14	0.35
225003	70.	0.28	0.70
225004	70.	0.19	0.46
225005	71.	0.28	0.69
225006	71.	0.31	0.76
225007	71.	0.25	0.61
225008	71.	0.17	0.41
225009	71.	0.23	0.56
225010	71.	0.06	0.15
225011	71.	0.05	0.13
225012	71.	0.06	0.14
225013	71.	0.67	1.64
225014	72.	0.57	1.39
225015	72.	0.25	0.60
225016	72.	0.26	0.63
225017	72.	0.10	0.24
225018	72.	0.24	0.59
225019	72.	0.46	1.12
225020	72.	0.21	0.51
225021	72.	0.12	0.29
225022	73.	0.08	0.20
225023	73.	0.40	0.98
225024	73.	0.29	0.70
225025	73.	0.17	0.42
225026	73.	0.10	0.25
225027	73.	0.19	0.46
225028	73.	0.15	0.37
225029	73.	0.27	0.67
225030	74.	0.46	1.13
225031	74.	0.57	1.41
225032	74.	0.18	0.45
225033	74.	0.34	0.83
225034	74.	0.12	0.28
225035	74.	0.12	0.30
225036	74.	0.04	0.09
225037	74.	0.05	0.13
225038	75.	0.43	1.06
225039	75.	0.14	0.34
225040	75.	0.11	0.26
225041	75.	0.07	0.17
225042	75.	0.24	0.59
225043	75.	0.17	0.43
225044	75.	0.38	0.92
225045	75.	0.46	1.12
225046	76.	0.27	0.66
225047	76.	0.50	1.22
225048	76.	0.16	0.40
225049	76.	0.24	0.58
225050	76.	0.21	0.52

MEAN=0.59

TABLE 4-8-E BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : 1.4MM MSH BASKET

SAMPLE DURATION = 120 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
226001	65.	0.64	0.78
226002	65.	0.53	0.65
226003	65.	0.68	0.83
226004	66.	1.00	1.23
226005	66.	0.54	0.66
226006	66.	0.20	0.25
226007	66.	0.57	0.70
226008	66.	0.93	1.13
226009	66.	0.32	0.39
226010	66.	0.23	0.28
226011	67.	0.45	0.56
226012	67.	0.68	0.83
226013	67.	0.64	0.78
226014	67.	0.16	0.19
226015	68.	0.32	0.40
226016	68.	0.34	0.42
226017	68.	0.08	0.10
226018	68.	0.11	0.13
226019	69.	0.13	0.16
226020	69.	0.33	0.41
226021	69.	0.86	1.06
226022	69.	0.82	1.00
226023	69.	0.56	0.68
226024	69.	0.98	1.21
226025	69.	0.84	1.03
226026	70.	0.27	0.33
226027	70.	0.20	0.24
226028	70.	0.66	0.81
226029	70.	0.48	0.59
226030	70.	0.16	0.20
226031	70.	0.31	0.38
226032	71.	0.11	0.13
226033	71.	0.33	0.41
226034	71.	0.30	0.36
226035	71.	0.27	0.34
226036	71.	0.68	0.83
226037	71.	0.36	0.44
226038	71.	0.66	0.81
226039	72.	0.83	1.08
226040	72.	0.71	0.87
226041	72.	0.20	0.24
226042	72.	0.85	1.04
226043	74.	0.64	0.78
226044	74.	0.14	0.17
226045	74.	0.83	1.02
226046	74.	0.09	0.11
226047	75.	0.46	0.57
226048	75.	0.33	0.40
226049	75.	0.67	0.82
226050	75.	0.37	0.46
			MEAN=0.59

TABLE 4-8-F BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : 1.4MM MSH BASKET
SAMPLE DURATION = 180 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
227001	79.	0.29	0.24
227002	79.	0.28	0.23
227003	79.	0.19	0.15
227004	79.	0.16	0.13
227005	79.	0.72	0.59
227006	79.	0.17	0.14
227007	80.	0.87	0.71
227008	80.	1.24	1.01
227009	80.	0.96	0.79
227010	80.	0.73	0.60
227011	80.	0.11	0.09
227012	80.	0.54	0.44
227013	80.	0.34	0.27
227014	80.	0.58	0.47
227015	80.	0.44	0.36
227016	80.	0.20	0.16
227017	80.	0.44	0.36
227018	81.	1.20	0.98
227019	81.	0.31	0.25
227020	81.	0.75	0.61
227021	81.	0.76	0.62
227022	81.	1.24	1.01
227023	81.	0.75	0.62
227024	81.	0.61	0.50
227025	82.	0.83	0.68
227026	82.	0.54	0.44
227027	82.	0.72	0.59
227028	82.	1.09	0.89
227029	82.	0.77	0.63
227030	82.	0.36	0.30
227031	71.	0.59	0.49
227032	71.	0.64	0.52
227033	71.	0.69	0.56
227034	71.	0.76	0.62
227035	72.	0.61	0.50
227036	72.	0.53	0.43
227037	72.	0.27	0.22
227038	72.	0.47	0.38
227039	72.	0.14	0.11
227040	72.	0.90	0.74
227041	73.	0.89	0.73
227042	73.	0.74	0.61
227043	73.	0.40	0.33
227044	73.	0.29	0.23
227045	73.	0.73	0.59
227046	73.	0.22	0.18
227047	74.	0.21	0.17
227048	74.	0.54	0.44
227049	74.	0.49	0.40
227050	74.	0.71	0.58

MEAN=0.47

TABLE 4-8-G

BED-LOAD SAMPLER DATA

FLOW CONDITION # 3
SAMPLER TYPE : 1.4MM MSH BASKET

SAMPLE DURATION = 10 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
321001	80.	0.10	1.50
321002	80.	0.85	12.49
321003	80.	0.89	13.04
321004	80.	0.21	3.09
321005	80.	0.60	8.88
321006	80.	0.43	6.27
321007	80.	0.16	2.33
321008	80.	0.27	4.01
321009	80.	0.57	8.39
321010	80.	0.32	4.74
321011	80.	0.37	5.45
321012	80.	0.09	1.32
321013	80.	0.11	1.65
321014	80.	0.16	2.30
321015	80.	0.67	9.92
321016	30.	0.14	2.05
321017	80.	0.19	2.85
321018	80.	0.14	2.05
321019	80.	0.24	3.46
321020	80.	0.11	1.62
321021	80.	0.26	3.86
321022	80.	0.47	6.92
321023	80.	0.59	8.63
321024	80.	0.37	5.42
321025	80.	0.18	2.66
321026	81.	0.22	3.27
321027	81.	0.63	9.30
321028	81.	0.18	2.60
321029	81.	0.23	3.37
321030	81.	0.20	2.94
321031	81.	0.59	8.63
321032	81.	0.23	3.37
321033	81.	0.16	2.30
321034	81.	0.31	4.62
321035	81.	0.09	1.25
321036	81.	0.55	8.02
321037	81.	0.20	2.91
321038	81.	0.39	5.66
321039	81.	0.12	1.71
321040	81.	0.43	6.40
321041	81.	0.44	6.49
321042	81.	0.32	4.74
321043	81.	0.53	7.83
321044	81.	0.46	6.70
321045	81.	0.28	4.13
321046	81.	0.36	5.33
321047	81.	0.18	2.60
321048	81.	0.57	8.45
321049	81.	1.15	16.86
321050	81.	0.09	1.32
			MEAN=5.11

TABLE 4-8-H BED-LOAD SAMPLER DATA

FLOW CONDITION # 3
SAMPLER TYPE : 1.4MM MSH BASKET
SAMPLE DURATION = 20 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
322001	77.	0.65	4.74
322002	77.	0.35	2.56
322003	77.	0.51	3.73
322004	77.	1.05	7.73
322005	77.	0.32	2.39
322006	77.	0.19	1.38
322007	77.	0.33	2.42
322008	77.	0.65	4.79
322009	77.	0.80	5.89
322010	77.	0.30	2.20
322011	77.	1.39	10.21
322012	77.	0.32	2.36
322013	77.	0.26	1.88
322014	78.	0.42	3.11
322015	78.	1.03	7.56
322016	78.	0.77	5.66
322017	78.	0.17	1.25
322018	78.	0.97	7.16
322019	78.	0.70	5.11
322020	78.	0.56	4.12
322021	78.	0.77	5.63
322022	78.	0.98	7.19
322023	78.	0.28	2.08
322024	78.	1.04	7.68
322025	78.	0.75	5.52
322026	78.	0.24	1.79
322027	78.	0.32	2.36
322028	78.	0.97	7.12
322029	78.	0.45	3.32
322030	78.	0.53	3.92
322031	78.	0.60	4.39
322032	78.	0.55	4.07
322033	78.	0.96	7.04
322034	78.	0.81	5.95
322035	78.	0.58	4.25
322036	78.	0.76	5.59
322037	78.	0.37	2.71
322038	79.	0.45	3.32
322039	79.	0.75	5.48
322040	79.	0.80	5.88
322041	79.	0.28	2.08
322042	79.	0.84	6.18
322043	79.	0.32	2.33
322044	79.	0.30	2.19
322045	79.	0.60	4.42
322046	79.	0.24	1.73
322047	79.	0.28	2.08
322048	79.	0.33	2.45
322049	79.	0.80	5.89
322050	79.	0.62	4.54
			MEAN=4.31

TABLE 4-8-I BED-LOAD SAMPLER DATA

FLOW CONDITION # 3
SAMPLER TYPE : 1.4MM MSH BASKET

SAMPLE DURATION = 30 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
323001	72.	0.62	3.03
323002	72.	0.65	3.17
323003	72.	0.78	3.84
323004	72.	0.53	2.61
323005	72.	0.77	3.77
323006	72.	0.49	2.42
323007	72.	0.85	4.16
323008	72.	0.78	3.85
323009	73.	0.36	1.76
323010	73.	1.68	8.22
323011	73.	1.02	5.02
323012	73.	0.31	1.50
323013	73.	1.15	5.65
323014	73.	1.31	6.41
323015	73.	0.42	2.06
323016	73.	1.38	6.78
323017	73.	1.14	5.61
323018	73.	1.45	7.11
323019	73.	0.33	1.60
323020	73.	0.90	4.41
323021	73.	0.63	3.10
323022	73.	0.55	2.71
323023	73.	1.08	5.30
323024	73.	1.23	6.04
323025	73.	0.32	1.55
323026	74.	0.45	2.19
323027	74.	0.31	1.51
323028	74.	2.07	10.15
323029	74.	0.91	4.46
323030	74.	0.28	1.38
323031	74.	0.27	1.31
323032	74.	0.67	3.26
323033	74.	0.33	1.60
323034	74.	1.33	6.53
323035	74.	0.53	2.59
323036	74.	0.89	4.36
323037	74.	0.60	2.93
323038	74.	0.64	3.13
323039	74.	0.77	3.78
323040	74.	1.75	8.60
323041	74.	0.89	4.36
323042	75.	0.83	4.05
323043	75.	0.87	4.28
323044	75.	0.54	2.64
323045	75.	0.41	2.03
323046	75.	1.07	5.26
323047	75.	0.98	4.83
323048	75.	0.23	1.14
323049	75.	0.58	2.85
323050	75.	0.41	2.00

MEAN= 3.86

FLOW CONDITION # 1
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 30 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
133001	66.	0.17	0.83
133002	66.	0.65	3.17
133003	66.	0.84	4.12
133004	66.	0.17	0.82
133005	66.	0.03	0.15
133006	66.	0.61	2.97
133007	67.	0.19	0.93
133008	67.	0.66	3.23
133009	67.	0.36	1.76
133010	67.	0.47	2.31
133011	67.	0.49	2.40
133012	67.	1.03	5.07
133013	67.	0.52	2.55
133014	67.	0.73	3.57
133015	67.	1.15	5.62
133016	67.	0.43	2.13
133017	68.	0.75	3.65
133018	68.	0.04	0.21
133019	68.	0.85	4.16
133020	68.	0.62	3.04
133021	68.	0.70	3.43
133022	68.	0.26	1.29
133023	70.	0.09	0.46
133024	70.	0.71	3.48
133025	70.	0.22	1.06
133026	70.	0.52	2.53
133027	70.	0.86	4.21
133028	70.	0.06	0.30
133029	70.	0.34	1.67
133030	70.	0.21	1.05
133031	70.	0.32	1.56
133032	70.	0.65	3.21
133033	70.	0.36	1.78
133034	71.	0.08	0.37
133035	71.	1.17	5.73
133036	71.	0.72	3.53
133037	71.	0.26	1.29
133038	71.	0.74	3.63
133039	71.	0.91	4.47
133040	71.	0.13	0.63
133041	71.	0.51	2.50
133042	71.	0.20	1.00
133043	71.	0.25	1.21
133044	72.	0.33	1.60
133045	72.	0.54	2.65
133046	72.	0.33	1.63
133047	72.	0.26	1.26
133048	72.	0.66	3.22
133049	72.	0.18	0.86
133050	72.	0.37	1.84

MEAN=2.32

FLOW CONDITION # 1
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 45 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
134001	64.	0.65	2.11
134002	64.	0.58	1.89
134003	64.	0.23	0.74
134004	64.	0.46	1.51
134005	64.	1.23	4.03
134006	65.	0.88	2.87
134007	65.	0.32	1.04
134008	65.	1.11	3.61
134009	65.	0.67	2.19
134010	65.	0.17	0.56
134011	65.	0.50	1.64
134012	65.	0.30	0.99
134013	65.	0.78	2.55
134014	66.	0.85	2.79
134015	66.	1.35	4.43
134016	66.	0.22	0.73
134017	66.	0.62	2.01
134018	66.	0.80	2.62
134019	66.	1.02	3.32
134020	66.	1.44	4.70
134021	66.	1.26	4.11
134022	67.	1.13	3.70
134023	67.	0.91	2.96
134024	67.	0.51	1.66
134025	67.	0.24	0.79
134026	67.	0.70	2.27
134027	67.	1.02	3.34
134028	67.	0.50	1.62
134029	67.	0.26	0.83
134030	68.	1.12	3.67
134031	68.	1.39	4.56
134032	68.	0.72	2.36
134033	68.	0.87	2.33
134034	68.	0.72	2.37
134035	68.	0.08	0.28
134036	68.	0.49	1.61
134037	68.	0.42	1.36
134038	69.	0.83	2.72
134039	69.	0.65	2.12
134040	69.	0.21	0.69
134041	69.	1.32	4.30
134042	69.	0.93	3.06
134043	69.	0.32	1.06
134044	69.	0.32	1.03
134045	69.	0.87	2.84
134046	70.	0.84	2.75
134047	70.	0.12	0.40
134048	70.	0.34	1.10
134049	70.	0.90	2.93
134050	70.	0.98	3.21
			MEAN=2.30

TABLE 4-9-C

BED-LOAD SAMPLER DATA

FLOW CONDITION # 1
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
135001	68.	1.54	3.79
135002	68.	1.45	3.56
135003	68.	1.35	3.31
135004	68.	0.23	0.56
135005	69.	1.01	2.47
135006	69.	1.04	2.56
135007	69.	1.20	2.94
135008	69.	0.74	1.82
135009	69.	1.38	3.39
135010	69.	1.26	3.09
135011	69.	1.18	2.90
135012	70.	0.08	0.20
135013	70.	1.28	3.15
135014	70.	0.11	0.27
135015	70.	0.73	1.79
135016	70.	1.36	3.33
135017	70.	0.62	1.53
135018	70.	1.83	4.48
135019	71.	1.15	2.83
135020	71.	1.22	3.00
135021	71.	0.94	2.30
135022	71.	0.96	2.36
135023	71.	0.56	1.36
135024	71.	1.15	2.83
135025	71.	0.84	2.06
135026	72.	1.32	3.22
135027	72.	0.77	1.90
135028	72.	1.25	3.06
135029	72.	1.30	3.18
135030	72.	1.00	2.45
135031	72.	0.61	1.49
135032	72.	0.44	1.09
135033	73.	1.19	2.91
135034	73.	1.30	3.17
135035	73.	0.64	1.56
135036	73.	1.19	2.91
135037	73.	1.27	3.12
135038	73.	0.53	1.30
135039	73.	1.17	2.87
135040	74.	1.38	3.39
135041	74.	0.57	1.39
135042	74.	1.00	2.45
135043	74.	1.14	2.79
135044	74.	1.04	2.54
135045	74.	0.14	0.34
135046	74.	0.69	1.69
135047	75.	0.99	2.44
135048	75.	1.56	3.84
135049	75.	0.88	2.14
135050	75.	1.16	2.85
			MEAN=2.44

FLOW CONDITION # 2
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 60 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
235001	67.	0.19	0.47
235002	67.	0.19	0.46
235003	67.	0.25	0.62
235004	67.	0.10	0.24
235005	67.	0.38	0.94
235006	68.	0.19	0.47
235007	68.	0.19	0.46
235008	68.	0.75	1.83
235009	68.	0.22	0.54
235010	68.	0.20	0.48
235011	68.	0.08	0.20
235012	68.	0.35	0.85
235013	68.	0.23	0.56
235014	68.	0.37	0.90
235015	71.	0.53	1.30
235016	71.	0.28	0.68
235017	71.	0.20	0.50
235018	71.	0.12	0.30
235019	71.	0.62	1.52
235020	71.	0.34	0.83
235021	72.	0.26	0.65
235022	72.	0.05	0.12
235023	72.	0.30	0.73
235024	72.	0.05	0.13
235025	72.	0.30	0.73
235026	72.	0.22	0.55
235027	72.	0.09	0.23
235028	72.	0.16	0.38
235029	72.	0.03	0.07
235030	72.	0.26	0.65
235031	72.	0.21	0.51
235032	72.	0.01	0.02
235033	73.	0.05	0.12
235034	73.	0.01	0.03
235035	73.	0.39	0.96
235036	73.	0.05	0.13
235037	73.	0.70	1.72
235038	73.	0.17	0.42
235039	73.	0.03	0.07
235040	73.	0.38	0.92
235041	73.	0.14	0.34
235042	73.	0.04	0.09
235043	73.	0.21	0.51
235044	73.	0.03	0.07
235045	74.	0.32	0.78
235046	74.	0.16	0.39
235047	74.	0.04	0.09
235048	74.	0.03	0.06
235049	74.	0.12	0.29
235050	74.	0.84	2.07

MEAN=0.56

TABLE 4-9-E

BED-LOAD SAMPLER DATA

FLOW CONDITION # 2
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 120 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
236001	75.	0.18	0.23
236002	75.	0.91	1.12
236003	75.	0.13	0.16
236004	75.	0.52	0.64
236005	76.	0.87	1.07
236006	76.	0.93	1.15
236007	76.	0.45	0.56
236008	76.	0.13	0.16
236009	76.	0.17	0.20
236010	76.	0.17	0.21
236011	76.	0.96	1.18
236012	77.	0.81	0.99
236013	77.	0.48	0.59
236014	77.	0.28	0.34
236015	77.	0.31	0.38
236016	73.	0.68	0.84
236017	73.	1.44	1.76
236018	73.	0.46	0.56
236019	73.	0.16	0.20
236020	73.	0.44	0.54
236021	74.	0.80	0.98
236022	74.	0.37	0.46
236023	74.	0.30	0.37
236024	74.	0.23	0.28
236025	74.	0.08	0.09
236026	74.	0.39	0.47
236027	74.	0.67	0.82
236028	74.	0.93	1.14
236029	75.	0.72	0.88
236030	75.	0.96	1.18
236031	75.	0.45	0.55
236032	75.	0.62	0.76
236033	75.	0.09	0.11
236034	75.	0.28	0.34
236035	75.	0.13	0.16
236036	75.	0.49	0.60
236037	75.	0.33	0.41
236038	76.	0.17	0.20
236039	76.	0.04	0.05
236040	76.	0.10	0.12
236041	76.	0.10	0.13
236042	76.	0.40	0.49
236043	76.	0.18	0.22
236044	76.	0.79	0.97
236045	76.	0.65	0.80
236046	77.	0.49	0.61
236047	77.	0.97	1.19
236048	77.	0.52	0.64
236049	77.	0.08	0.10
236050	77.	0.89	1.09

MEAN=0.58

FLOW CONDITION # 2
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 180 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
237001	70.	1.01	0.83
237002	70.	0.76	0.62
237003	70.	1.35	1.10
237004	71.	0.78	0.64
237005	71.	0.36	0.30
237006	71.	0.61	0.50
237007	71.	0.95	0.78
237008	71.	0.68	0.56
237009	71.	0.66	0.54
237010	72.	0.55	0.45
237011	72.	0.77	0.63
237012	73.	1.22	1.00
237013	73.	0.93	0.76
237014	73.	0.82	0.67
237015	73.	0.22	0.18
237016	73.	0.45	0.37
237017	74.	0.11	0.09
237018	74.	0.81	0.66
237019	74.	0.68	0.55
237020	74.	1.12	0.91
237021	74.	0.17	0.14
237022	74.	0.83	0.68
237023	75.	0.18	0.15
237024	75.	0.98	0.80
237025	75.	0.51	0.42
237026	75.	0.70	0.57
237027	75.	0.60	0.49
237028	75.	0.79	0.64
237029	76.	0.89	0.72
237030	76.	0.44	0.36
237031	76.	0.43	0.35
237032	79.	1.15	0.94
237033	79.	0.80	0.65
237034	79.	1.27	1.04
237035	79.	0.95	0.78
237036	79.	0.71	0.58
237037	80.	0.20	0.16
237038	80.	0.61	0.50
237039	80.	0.07	0.06
237040	80.	0.41	0.34
237041	80.	0.77	0.63
237042	80.	0.45	0.37
237043	80.	0.35	0.29
237044	80.	0.52	0.42
237045	80.	0.49	0.40
237046	81.	0.58	0.48
237047	81.	0.90	0.74
237048	81.	0.68	0.56
237049	81.	0.50	0.41
237050	81.	0.83	0.68

MEAN=**0.55**

FLOW CONDITION # 3 SAMPLE DURATION = 10 SEC
SAMPLER TYPE : 2.4MM MSH BASKET SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
331001	73.	0.21	3.05
331002	73.	0.17	2.57
331003	73.	0.34	5.07
331004	73.	0.31	4.59
331005	73.	0.29	4.23
331006	73.	0.40	5.95
331007	73.	0.18	2.66
331008	73.	0.11	1.60
331009	73.	0.40	5.89
331010	73.	0.69	10.14
331011	73.	0.41	6.04
331012	73.	0.79	11.59
331013	73.	0.32	4.77
331014	74.	0.29	4.29
331015	74.	0.42	6.22
331016	74.	0.41	6.07
331017	74.	0.44	6.40
331018	74.	0.83	12.19
331019	74.	0.22	3.20
331020	74.	0.25	3.62
331021	74.	0.26	3.83
331022	74.	0.63	9.21
331023	74.	0.28	4.04
331024	74.	0.23	3.44
331025	74.	0.13	1.96
331026	74.	0.35	5.19
331027	74.	0.27	3.92
331028	74.	0.09	1.39
331029	74.	0.71	10.38
331030	74.	0.40	5.89
331031	74.	0.30	4.47
331032	74.	0.51	7.46
331033	74.	0.44	6.46
331034	74.	0.39	5.73
331035	74.	0.11	1.69
331036	74.	0.34	5.04
331037	74.	0.58	8.48
331038	74.	0.78	11.41
331039	75.	0.14	2.05
331040	75.	0.29	4.20
331041	75.	0.17	2.57
331042	75.	0.68	10.02
331043	75.	0.08	1.21
331044	75.	0.78	11.47
331045	75.	0.16	2.32
331046	75.	0.45	6.64
331047	75.	0.44	6.49
331048	75.	0.28	4.04
331049	75.	0.62	9.06
331050	75.	0.25	3.65
			MEAN=5.48

FLOW CONDITION # 3
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 20 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
332001	69.	0.18	1.34
332002	69.	0.50	3.67
332003	69.	0.57	4.20
332004	69.	0.34	2.54
332005	69.	0.14	1.03
332006	70.	0.71	5.21
332007	70.	0.77	5.63
332008	70.	0.54	3.95
332009	70.	0.38	2.79
332010	70.	0.69	5.09
332011	70.	0.94	6.90
332012	70.	0.53	3.86
332013	70.	0.49	3.64
332014	70.	0.37	2.75
332015	71.	0.14	1.04
332016	71.	0.51	3.77
332017	71.	0.38	2.79
332018	71.	0.30	2.22
332019	71.	0.72	5.30
332020	71.	1.05	7.70
332021	72.	0.91	6.70
332022	72.	0.38	2.81
332023	72.	0.33	2.40
332024	72.	0.94	6.94
332025	72.	0.23	1.69
332026	72.	1.24	9.09
332027	72.	0.86	6.29
332028	72.	0.46	3.35
332029	72.	0.65	4.77
332030	72.	0.78	5.75
332031	72.	1.02	7.52
332032	72.	0.65	4.77
332033	72.	1.32	9.73
332034	72.	1.30	9.58
332035	72.	0.44	3.20
332036	73.	0.33	2.46
332037	73.	1.03	7.58
332038	73.	1.04	7.65
332039	73.	0.13	0.92
332040	73.	0.16	1.18
332041	73.	1.41	10.40
332042	73.	0.83	6.10
332043	73.	0.33	2.46
332044	73.	0.48	3.53
332045	73.	0.55	4.01
332046	73.	0.28	2.08
332047	73.	0.82	6.02
332048	73.	0.09	0.65
332049	73.	0.52	3.79
332050	73.	1.33	9.75

MEAN=4.57

TABLE 4-9-I BED-LOAD SAMPLER DATA

FLOW CONDITION # 3
SAMPLER TYPE : 2.4MM MSH BASKET

SAMPLE DURATION = 30 SEC
SAMPLE INTERVAL = 90 SEC

SAMPLE ID NUMBER	WATER TEMP DEG-F	SAMPLER CATCH LBS	TRANSPORT RATE LB/(MIN-FT)
333001	72.	1.38	6.74
333002	72.	0.62	3.06
333003	72.	1.32	6.48
333004	72.	0.24	1.19
333005	72.	1.08	5.30
333006	72.	1.02	5.01
333007	73.	0.75	3.67
333008	73.	2.00	9.79
333009	73.	0.61	3.00
333010	73.	0.92	4.52
333011	73.	0.72	3.55
333012	73.	0.77	3.78
333013	73.	0.43	2.11
333014	73.	0.48	2.35
333015	73.	1.54	7.54
333016	73.	1.43	7.03
333017	73.	0.49	2.42
333018	73.	0.97	4.74
333019	74.	1.03	5.05
333020	74.	1.08	5.31
333021	74.	1.34	6.56
333022	74.	0.46	2.23
333023	74.	0.86	4.20
333024	74.	0.67	3.29
333025	74.	0.49	2.42
333026	74.	0.51	2.52
333027	75.	1.18	5.78
333028	75.	0.87	4.29
333029	75.	0.69	3.39
333030	75.	1.20	5.89
333031	75.	0.53	2.62
333032	75.	2.05	10.06
333033	75.	1.42	6.98
333034	75.	0.44	2.16
333035	75.	1.27	6.24
333036	75.	1.20	5.87
333037	75.	0.65	3.19
333038	75.	0.23	1.11
333039	76.	0.81	3.95
333040	76.	0.54	2.66
333041	76.	1.10	5.37
333042	76.	0.86	4.20
333043	76.	0.39	1.91
333044	76.	0.40	1.98
333045	76.	1.17	5.71
333046	76.	0.88	4.32
333047	76.	1.02	4.99
333048	77.	0.84	4.09
333049	77.	0.35	1.73
333050	77.	0.56	2.76
			MEAN=4.30

TABLE 5-1 TRANSPORT RATES COMPUTED FROM THE EQUATION OF MEYER-PETER, MULLER (1948)

(1) Flow Condition No.	(2) Calculations for	(3) R ft	(4) V fps	(5) S	(6) $R^{2/3}$	(7) $S^{1/2}$	(8) K_b	(9) $\left(\frac{K_b}{K_b'}\right)^{3/2}$	(10) $62.4\ RS\left(\frac{K_b}{K_b'}\right)^{3/2}$	(11) $.312 g_s'^{2/3}$	(12) g_s' $\frac{lbs}{ft/sec}$	(13) g_s $\frac{lbs}{ft/min}$	(14) G_s $\frac{lbs}{min}$	(15) C ppm
1	X-Sect Average	.58	2.60	.0046	.694	.068	55.1	.730	.121	.035	.037	2.22	8.84	394
	Centre-line	.58	3.34	.0046	.694	.068	70.8	1.06	.176	.090	.154	9.24	-	1274
2	X-Sect Average	.57	2.47	.0029	.686	.054	66.7	.972	.100	.014	.010	.60	2.39	114
	Centre-line	.57	2.78	.0029	.686	.054	75.0	1.16	.120	.034	.036	2.16	-	364
3	X-Sect Average	.56	3.14	.0050	.678	.071	65.2	.939	.164	.078	.125	7.50	29.9	1141
	Centre-line	.56	3.57	.0050	.678	.071	74.2	1.14	.199	.113	.218	13.1	-	1750

TABLE 5-2 TRANSPORT RATES COMPUTED FROM THE MODIFIED EINSTEIN TECHNIQUE OF COLBY AND HUBBELL (1961)

(1) Flow Condition No.	(2) Calculations for	(3) h	(4) $\frac{xh}{k_s}$	(5) V	(6) $\sqrt{(RS)_m}$	(7) $(RS)_m$	(8) $\sum i_b \Phi_* D^{3/2} \times 10^7$	(9) b	(10) G_s $\frac{lb}{min}$	(11) g_s $\frac{lb}{min\text{-}ft}$	(12) C ppm
1	X-Sect Average	.58	28.2	2.60	.0316	.00100	163	4	2.34	-	104
	Centre-line	.58	28.2	3.34	.0405	.00164	1460	1	-	5.26	725
2	X-Sect Average	.57	27.7	2.47	.0298	.00089	82.5	4	1.18	-	56.3
	Centre-line	.57	27.7	2.78	.0337	.00114	328	1	-	1.18	199
3	X-Sect Average	.56	27.2	3.14	.0380	.00144	917	4	13.2	-	504
	Centre-line	.56	27.2	3.57	.0430	.00185	2220	1	-	7.99	1070

TABLE 5-3 SAMPLE CALCULATION USING MODIFIED EINSTEIN PROCEDURE

Flow Condition #1 Centreline $(RS)_m = .00164$

(1) Size Range ft	(2) i_b %	(3) D ft	(4) $D^{3/2}$	(5) Ψ_m	(6) Φ_*	(7) $i_b * D^{3/2}$ X10^7
.05	1	-	-	-	-	-
.05 - .0334	7	.0409	.00825	16.3	.011	63.5
.0034 - .0250	17	.0289	.00493	11.5	.054	453
.0250 - .0167	22	.0204	.00287	9.8	.090	568
.0167 - .00835	25	.0118	.00128	9.8	.090	288
.00835 - .00328	25	.0052	.00038	9.8	.090	85.5
.00328	3	-	-	-	-	-

$$\sum i_b \Phi_* \ D^{3/2} = 1458 \times 10^{-7}$$

TABLE 5-5 TRANSPORT RATE DISTRIBUTION DATA *

(1) Flow Condition No.	(2) Sample Duration	(3) Average Indicated Transport Rate lb/(min-ft)	(4) Standard Deviation lb/(min-ft)	(5) Coefficient of Variation percent	(6) Median Transport Value lb/(min-ft)	(7) Range of Transport Rates lb/(min-ft)
1	30	6.23	4.29	68.9	5.68	0.20 - 16.31
	45	6.38	2.83	44.4	6.10	1.31 - 13.95
	60	6.18	2.46	39.8	5.92	1.77 - 11.78
2	60	2.10	1.66	79.0	1.55	0.02 - 8.87
	120	1.89	1.17	61.9	1.88	0.34 - 5.47
	180	1.90	0.94	49.5	1.85	0.38 - 4.68
3	10	9.83	8.06	82.0	7.41	0.21 - 31.56
	20	11.65	6.74	57.8	10.87	1.38 - 33.11
	30	9.71	6.05	62.3	8.72	1.44 - 29.53

* Based on Slice Sampler Data

TABLE 5-6 SUMMARY OF COMPARISON OF MEANS TEST *

(1) Flow Condition No.	FIRST SAMPLE MEANS				SECOND SAMPLE MEANS				(10) θ Degrees	(11) Calculated d Value	(12) Approximate Tabulated d Value
	(2) Duration sec	(3) $\bar{X}_1$ lb/(min-ft)	(4) $S_{\bar{x}1}$ lb/(min-ft)	(5) V_1	(6) Duration sec	(7) $\bar{X}_2$ lb/(min-ft)	(8) $S_{\bar{x}2}$ lb/(min-ft)	(9) V_2			
1	45	6.38	2.83	49	30	6.23	4.29	49	33.4	.03	2.0
	45	6.38	2.83	49	60	6.18	2.46	49	49.0	.05	2.0
	30	6.23	4.29	49	60	6.13	2.46	49	60.1	.01	2.0
2	60	2.10	1.66	49	120	1.89	1.17	49	54.8	.10	2.0
	60	2.10	1.66	49	180	1.90	0.94	49	60.5	.10	2.0
	180	1.90	0.94	49	120	1.89	1.17	49	38.8	.01	2.0
3	20	11.65	6.74	49	10	9.83	8.06	49	40.0	.17	2.0
	20	11.65	6.74	49	30	9.71	6.05	49	48.0	.21	2.0
	10	9.83	8.06	49	30	9.71	6.05	49	53.1	.01	2.0

* Based on Slice Sampler Data

TABLE 5-8 SUMMARY OF INDICATED AVERAGE SAMPLER EFFICIENCIES

(1) Flow Condition No.	(2) Average Transport Rate* lb/(min-ft)	(3) Basket Type	(4) Duration sec	(5) Indicated Transport Rate lb/(min-ft)	(6) Sampling Efficiency percent
1	6.26	1.4 mm	30	2.31	36.9
			45	2.28	36.4
			60	2.08	33.2
		2.4 mm	30	2.32	37.1
			45	2.30	36.7
			60	2.44	39.0
2	1.96	1.4 mm	60	0.59	30.1
			120	0.59	30.1
			180	0.47	24.0
		2.4 mm	60	0.56	28.6
			120	0.58	29.6
			180	0.55	28.1
3	10.40	1.4 mm	10	5.11	49.1
			20	4.31	41.4
			30	3.86	37.1
		2.4 mm	10	5.48	52.7
			20	4.57	43.9
			30	4.30	41.3

* without correction for fine-material deficiency

TABLE 5-9 SUMMARY OF EFFICIENCY CHANGES WITH DURATION

(1) Flow Condition No.	(2) Duration sec	(3) 1.4 mm Mesh Basket		(4) 2.4 mm Mesh Basket	
		(a) Average Sampler Catch lbs	(b) Efficiency Change from Shortest Duration percent	(c) Average Sampler Catch lbs	(d) Efficiency Change from Shortest Duration percent
1	30	.47	-	.47	-
	45	.70	-0.5	.70	-0.4
	60	.85	-3.7	1.00	+1.9
2	60	.24	-	.23	-
	120	.48	0.0	.47	+1.0
	180	.58	-6.1	.67	-0.5
3	10	.35	-	.37	-
	20	.59	-7.7	.62	-8.8
	30	.79	-12.0	.88	-11.4

TABLE 5-10 SCALING UP OF MODEL SAMPLER EFFICIENCY RESULTS

(1) Sampler Basket Size	(2) Flow Condition No.	(3) Model Mean Transport Rate g_{sm} lb/(min-ft)	(4) Prototype Mean Transport Rate g_{sp} lb/(min-ft)	(5) Model Sampler Catch Rate* C_{rm} lb/min	(6) Prototype Sampler Catch Rate C_{rp} lb/min	(7) Sampling Efficiency E percent
1.4 mm Model and 1/4 inch Prototype	1	6.26	70.0	0.94	52.6	36.9
	2	1.96	21.9	0.24	13.4	30.1
	3	10.40	116.3	2.08	116.3	49.1
2.4 mm Model and 1/2 inch Prototype	1	6.26	70.0	0.95	53.1	37.1
	2	1.96	21.9	0.23	12.9	28.6
	3	10.40	116.3	2.24	125.2	52.7

* "Catch Rate" was determined by dividing sampler catch by sampling duration.

TABLE 5-11 RE-CALCULATION OF BED-LOAD TRANSPORT DATA FOR ELBOW RIVER AT BRAGG CREEK, 1967-69

Data by Hollingshead and Samide					Revised on Basis of Experimental Results		
(1) Date	(2) Average Discharge for Sample Period cfs	(3) No. of Samples	(4) Width of Active Bed Movement ft	(5) Catch Rate lb/min	(6) Estimated Transport Rate lb/min-ft	(7) Estimated Coarse Material Bed-Load lb/min	(8) Estimated Total Bed Load lb/min*
1-6-1967	3,850	1	60	33.00	48.3	2898.0	4140.0
2-6-1967	2,900	13	50	20.84	32.5	1625.0	2321.4
17-6-1967	1,900	8	80	11.40	19.2**	1536.0	2194.3
20-6-1967	1,630	13	40	3.60	7.5**	300.0	428.6
21-6-1967	1,560	12	50	7.44	13.4**	670.0	957.1
22-6-1967	1,470	7	40	6.90	12.6**	504.0	720.0
23-6-1967	1,250	3	30	.07	2.0**	60.0	85.7
8-6-1968	1,490	17	40	7.40	13.3**	532.0	760.0
9-6-1968	1,400	22	30	1.73	4.6**	138.0	197.1
10-6-1968	1,370	5	20	2.70	6.1**	122.0	174.3
25-6-1969	2,900	11	40	48.80	66.5	2660.0	3800.0
26-6-1969	3,200	11	30	60.13	78.0	2340.0	3342.9
27-6-1969	2,400	23	50	44.00	61.3	3065.0	4378.6
27-6-1969	2,200	26	50	22.48	34.8	1740.0	2485.7
28-6-1969	2,250	32	50	29.33	44.4	2220.0	3171.4
30-6-1969	3,360	11	40	49.85	67.7	2708.0	3868.6
30-6-1969	3,180	26	50	62.40	80.1	4005.0	5721.4
1-7-1969	3,000	26	40	48.20	65.9	2636.0	3765.7
1-7-1969	2,900	29	40	70.50	87.3	3492.0	4988.6
2-7-1969	2,450	55	50	22.28	34.5	1725.0	2464.3
3-7-1969	2,200	28	50	18.76	29.7	1485.0	2121.4
3-7-1969	2,100	15	40	9.05	15.8**	632.0	902.9
4-7-1969	2,100	27	50	9.00	15.7**	785.0	1121.4
5-7-1969	2,200	19	50	5.24	10.0**	500.0	714.3

* These figures are generally higher than given by Hollingshead (1971) because a constant efficiency of 45% was formerly assumed.

** These values were estimated by extrapolating the curve of the 1/4 in. mesh basket (FIG. 5-9-B) to zero catch rate.

APPENDIX C - PHOTOGRAPHS

PLATE 1-1

SIDE VIEW OF LARGE BASKET SAMPLER WITH ¼ INCH MESH BASKET

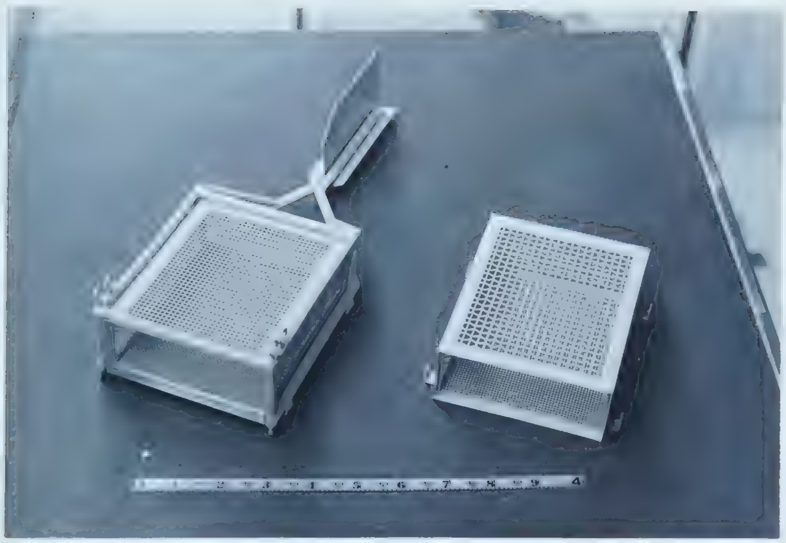


PLATE 3-1

1:5 SCALE MODEL SAMPLER USED IN FLUME TESTING

PLATE 3-2

UPSTREAM VIEW OF FLUME SET-UP

PLATE 3-3

SEDIMENT INJECTION TANK LOCATED AT UPSTREAM END OF FLUME

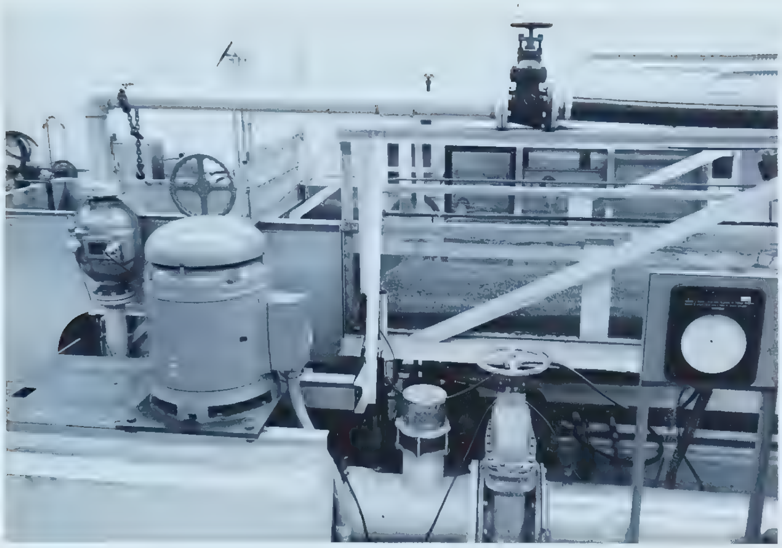


PLATE 3-4

SIDE VIEW OF DOWNSTREAM END OF FLUME

PLATE 3-5

VIEW OF CARRIAGE WITH BED SENSING AND WATER SURFACE SENSING PROBES

PLATE 3-6

OVER-HEAD VIEW OF SLICE SAMPLER LOCATED IN END SLOT

PLATE 3-7

SLICE SAMPLER DISCHARGE

PLATE 3-8
CART SAMPLER IN SAMPLING POSITION AT UPSTREAM END

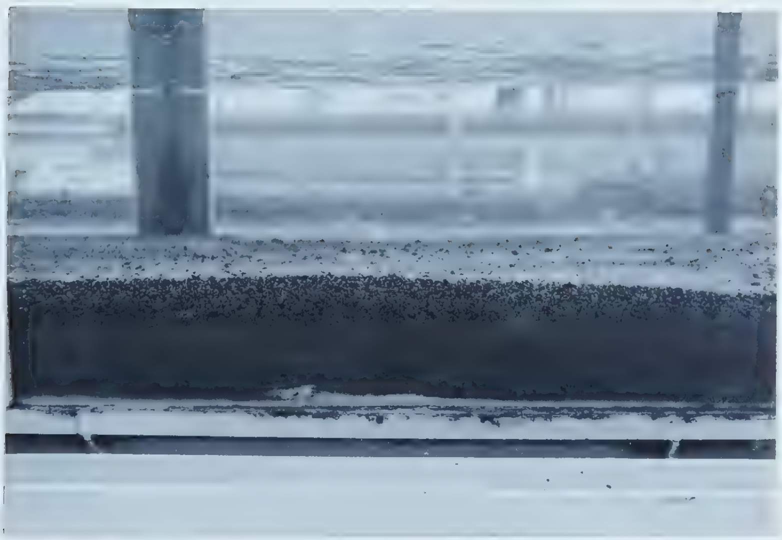


PLATE 4-1
BED LAYERING DURING FLOW CONDITION NO. 3

PLATE 4-2

BED CONFIGURATION DURING FLOW CONDITION NO.1

PLATE 4-3

BED CONFIGURATION DURING FLOW CONDITION NO.2

PLATE 4-4

BED CONFIGURATION DURING FLOW CONDITION NO. 3